(Pre-)Alpine Grasslands and People:
Perceptions of Ecosystem Services, Values, and Spatial Distribution

Dissertation

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Abstract

Grasslands are widely distributed across the globe, covering almost a third of the world's terrestrial surface. Particularly in Alpine and pre-Alpine environments, grasslands have been the dominant agricultural land use for centuries. Besides fodder production, grasslands supply various other benefits to people, such as carbon sequestration, erosion control, or recreation. However, the direct and indirect benefits people obtain from landscape and nature - referred to as ecosystem services - are deteriorating globally. Particularly, in (pre-)Alpine grasslands, ecosystem services are threatened due to management intensification, abandonment, and conversion into cropland. Incorporating the multiple values of ecosystems into management practices and policies can be very important for sustainable land use decisions. Besides monetary values, a large body of literature has recently evolved on the socio-cultural values of ecosystem services, including the study of relational values. However, the study of those is still in its infancy, which is addressed in this dissertation. This thesis further contributes to the study of ecosystem services by focusing on grasslands, acknowledging the gap in literature on ecosystem service and valuation research compared to other ecosystems. Hence, the goal of this dissertation is to investigate the socio-cultural values of farmers and citizens as well as the actual supply of (pre-)Alpine grassland ecosystem services. In Paper 1, differences in the perceived importance of ecosystem services between and among farmers and citizens were investigated. Paper 2 analyzed citizens' specific values of grasslands. Finally, Paper 3 determined synergies and trade-offs of the actual supply of ecosystem service.

The main study area was the Ammer watershed in southern Bavaria, Germany. It consists of a pre-Alpine hilly environment in the northern part and an Alpine, mountainous environment in the south. The agricultural land use is strongly dominated by grasslands, which is typical for (pre-)Alpine landscapes in Europe. The socio-cultural valuation of ecosystem services in Paper 1 and 2 was based on survey data collected in 2018 and 2020. Farmers (n=251) filled out the surveys while visiting the regional agricultural office. Citizens (n=1138) living in a 3 km radius of randomly selected points were invited by direct mail to answer the online survey. The surveys included questions on perceptions of ecosystem services and social characteristics of the respondents including socio-economic (e.g., occupation) and socio-demographic characteristics (e.g., age, gender), farm characteristics, or environmental attitude. Citizens also marked up to seven points on a map where they perceived grasslands to be "especially valuable" and could provide an explanation for this selection. In Paper 3, the supply of recreation was approximated by Photo-User-Days from geo-tagged photos, fodder production by yield, and habitat / regulating ecosystem services by agri-environmental payments. Various analytical techniques were used in the three papers to collate and analyze the different data types. Multivariate ordinations and regression were applied to understand relationships between the variables. Qualitative Content Analysis derived specific values of grasslands, namely instrumental (e.g., economic utility), intrinsic (e.g., biodiversity as sake for itself), and relational values (e.g., recreation, sense of place). Getis-Ord Gi* hotspot analyses were used to display spatial patterns.

The results of the individual studies revealed several novel insights regarding the importance of (pre-)Alpine grasslands to people. In Paper 1, the respondents placed overall high importance on the ecosystem services of grasslands. Nevertheless, significant mismatches in the perceptions existed between farmers and citizens, for instance regarding fodder production and recreation. Social characteristics, farm characteristics, and environmental attitudes also marked heterogeneity within the groups of farmers and citizens. Unraveling specific values in Paper 2

showed that grasslands and their ecosystem services were valued for a variety of reasons in different locations. Compared to instrumental and intrinsic values, relational values were represented most frequently. The analysis also showed a clear relationship between specific values and perceptions of ecosystem services. To illustrate, people who attributed instrumental values to grasslands also perceived them as suitable to supply provisioning services. The specific values also varied in space, indicating trade-offs between instrumental and intrinsic values. In Paper 3, analyses of the supply of ecosystem services also revealed trade-offs between yield and agri-environmental payments. Furthermore, recreation on grasslands was slightly influenced by management intensity, but also appeared to be co-produced by environmental and infrastructural factors.

By synthesizing the results of the three studies, the dissertation unraveled a link between actors' conflicting socio-cultural values and trade-offs in the actual supply of ecosystem services: areas with grasslands of instrumental value overlapped with areas of high yield. Hotspots of intrinsic values close to peatlands and mountainous regions overlapped with high agri-environmental payments and lower yields. The results also point to the important role of relational values that spatially overlapped with both intrinsic and instrumental values. In recent literature, relational values have been emerging as important ways to capture the many non-substitutable ways people engage with nature. In this study, we found that actively spending time on grasslands may nurture stewardship for nature. As the actual supply of ecosystem services revealed that both extensively and intensively managed grasslands were frequently visited for recreation, the results clearly show the high importance of maintaining grasslands to foster human-nature relationships. The dissertation also finds that agri-environmental policies providing incentives for extensive management can foster recreation and relational values, and further discusses the given limitations.

It can be concluded that grasslands constitute a variety of important ecosystem services to both farmers and citizens. Understanding and considering the multiple values of grassland ecosystem services, specifically relational values, can be vital for sustainable land use decisions and policy-making processes. The approach can help to understand which people are more likely to benefit or lose from decisions about agricultural management, economic development, or biodiversity conservation, and can provide important information for land use prioritization and management advice.

Zusammenfassung

Grünland ist weltweit stark verbreitet und bedeckt fast ein Drittel der terrestrischen Oberfläche. Insbesondere in alpinen und voralpinen Gebieten ist Grünland seit Jahrhunderten die vorherrschende landwirtschaftliche Nutzung. Neben Futtermittelproduktion bietet das Ökosystem Grünland weitere Leistungen wie Kohlenstoffbindung, Erosionsschutz oder Erholungsmöglichkeiten. Die direkten und indirekten Leistungen, die Menschen aus Landschaft und Natur ziehen – sogenannte Ökosystemleistungen – verschlechtern sich jedoch weltweit. Im (vor-)alpinen Grünland sind Ökosystemleistungen durch Intensivierung der Bewirtschaftung, Nutzungsaufgabe und Grünlandumwandlung gefährdet. Um nachhaltige Landnutzungsentscheidungen zu treffen ist es wichtig, den Wert, den das Ökosystem für Menschen bietet, in Bewirtschaftung und Politikmaßnahmen einzubeziehen. Zuletzt hat sich umfangreiche Literatur etabliert, die sich neben dem monetären Wert mit soziokulturellen Werten von Ökosystemleistungen befasst. Speziell die Forschung zu relationalen Werten von Natur und Ökosystemleistungen, die die vielfältigen Beziehungen zwischen Menschen und Natur beschreiben, steckt jedoch noch in der Anfangsphase. Desweiteren besteht eine Forschungslücke bezüglich des Kenntnisstandes zu Ökosystemleistungen von Grünland, welche verglichen zu anderen Ökosystemen noch wenig erforscht sind. Ziel der Dissertation war es daher, die soziokulturellen Werte von Landwirten und Bürgern sowie die tatsächliche Bereitstellung von Ökosystemleistungen (vor-)alpinen Grünlands zu analysieren. In Paper 1 wurden die Unterschiede zwischen Landwirten und Bürgern bezüglich der Bedeutung von Ökosystemleistungen untersucht. Paper 2 deckte die spezifischen Werte auf, die Bürgern mit Grünland assoziieren. Schließlich wurden in Paper 3 Synergien und Zielkonflikte bei der tatsächlichen Bereitstellung von Grünland Ökosystemleistungen analysiert.

Das Hauptuntersuchungsgebiet der Dissertation war im Einzugsgebiet der Ammer in Südbayern, Deutschland. Die Region besteht aus einer hügeligen Voralpenlandschaft in dem nördlichen Teil und einer alpinen, bergigen Landschaft im Süden. Grünland dominiert dort stark die landwirtschaftliche Nutzung, was für voralpine und alpine Landschaften in Europa typisch ist. Die soziokulturelle Bewertung von Ökosystemleistungen in Paper 1 und 2 basierte auf Umfragen, die im Jahr 2018 und 2020 erhoben wurden. Landwirte (n=251) beantworteten die Umfragen beim Besuch des regionalen Landwirtschaftsamtes. Bürger (n=1138), die in einem Umkreis von 3 km um zufällig ausgewählte Orte lebten, erhielten per Postwurfsendung einen Link mit der Einladung zur Teilnahme an einer Online-Umfrage. In den Umfragen wurden die Wahrnehmung von Ökosystemleistungen sowie die Charakterisierung der Befragten, einschließlich sozioökonomischer (z.B. Beruf) und soziodemografischer Merkmale (z.B. Alter, Geschlecht), Betriebsmerkmale von Landwirten und Umwelteinstellungen von Bürgern erfasst. Die befragten Bürger kartierten ergänzend bis zu sieben Punkte, wo sie Grünland als „besonders wertvoll" wahrnehmen, und konnten eine Erklärung für diese Auswahl angeben. In Paper 3 wurde die Ökosystemleistung Erholung durch die Anzahl geo-referenzierter Fotos auf Grünland abgeschätzt, Futterproduktion durch Erträge des Grünlands und Habitat sowie regulierende Ökosystemleistungen durch Agrarumweltzahlungen. Zur Analyse der Daten wurden multivariate Ordination und Regression genutzt um Zusammenhänge zwischen den Variablen zu analysieren. Eine qualitative Inhaltsanalyse leitete spezifische Werte von Grünland ab, nämlich instrumentelle (z.B. wirtschaftlicher Nutzen), intrinsische (z.B. Biodiversität als Selbstzweck) und relationale Werte (z.B. Erholung, Gefühl der Ortszugehörigkeit). Getis-Ord Gi* Hotspot-Analysen wurden angewandt, um räumliche Muster darzustellen.

Die Ergebnisse der einzelnen Studien lieferten fundierte Erkenntnisse über die Bedeutung von (vor-)alpinem Grünland. In Paper 1 wurde insgesamt eine hohe Bedeutung der Ökosystemleistungen von Grünland von den Befragten festgestellt. Dennoch gab es bezüglich der Wichtigkeit der Ökosystemleistungen signifikante Unterschiede zwischen Landwirten und Bürgern, beispielswiese bei Futterproduktion und Erholung. Auch innerhalb der Gruppen von Landwirten und Bürgern zeigte sich eine Heterogenität, angelehnt an sozialen Merkmalen, Betriebsstrukturen und Umwelteinstellungen. Die Aufschlüsselung spezifischer Werte in Paper 2 verdeutlichte, dass Grünland und seine Ökosystemleistungen aus unterschiedlichen Gründen an verschiedenen Orten geschätzt wurden. Im Vergleich zu instrumentellen und intrinsischen Werten wurden relationale Werte am häufigsten genannt. Die Studie zeigte auch einen Zusammenhang zwischen spezifischen Werten von Grünland und der Wichtigkeit von Ökosystemleistungen. Zum Beispiel empfanden Menschen, die instrumentelle Werte nannten, Grünland auch als besonders geeignet für bereitstellende Ökosystemleistungen (wie Futterproduktion). Die spezifischen Werte variierten auch räumlich, was auf eine Dichotomie zwischen instrumentellen und intrinsischen Werten in Grünland hinwies. In Paper 3 zeigten Analysen der Bereitstellung von Ökosystemleistungen auch Zielkonflikte auf. Darüber hinaus ergaben die Ergebnisse der Studie, dass Grünland für Freizeitaktivitäten stark genutzt werden. Neben der Bewirtschaftungsintensität stellten besonders Umwelt- und Infrastrukturfaktoren einen Zusammenhang mit Erholung dar.

Durch die Synthese der Ergebnisse der drei Studien konnte die Dissertation einen Zusammenhang zwischen den gegensätzlichen sozio-kulturellen Werten von Ökosystemleistungen und den tatsächlichen Zielkonflikten bei der Bereitstellung dieser aufdecken: Gebiete mit Grünland von instrumentellem Wert überlappten mit Gebieten hoher Futtererträge. Intrinsische Werte, die häufig in der Nähe von Mooren und Bergregionen auftraten, überlappten mit hohen Agrarumweltzahlungen und niedrigeren Erträgen. Die Ergebnisse weisen auch auf die wichtige Rolle von relationalen Werten hin, die räumlich sowohl mit intrinsischen als auch mit instrumentellen Werten übereinstimmten. In neuester Literatur wurden relationale Werte, die die diversen, nicht ersetzbaren Beziehungen zwischen Menschen und Natur beschreiben, immer wichtiger. Da sowohl extensiv als auch intensiv bewirtschaftete Grünlandflächen häufig für Freizeitaktivitäten genutzt wurden, zeigen die Ergebnisse deutlich die hohe Bedeutung des Erhalts von Grünland zur Förderung von Mensch-Umwelt Beziehungen. Außerdem deuten die Ergebnisse der Dissertation darauf hin, dass Politikmaßnahmen, die Anreize für extensive Bewirtschaftung bieten, Freizeitaktivitäten sowie Mensch-Umwelt Beziehungen fördern können.

Aus den Ergebnissen dieser Dissertation kann gefolgert werden, dass Wiesen und Weiden eine Vielzahl wichtiger Ökosystemleistungen sowohl für Landwirte als auch für Bürger erbringen. Das Verständnis und die Berücksichtigung der vielfältigen Werte von Ökosystemleistungen des Grünlands, insbesondere der relationalen Werte, kann für nachhaltige Landnutzungs-entscheidungen und politische Entscheidungsprozesse von entscheidender Bedeutung sein. Der Ansatz der Dissertation verschafft Einblicke, ob Menschen eher von Entscheidungen über landwirtschaftliche Bewirtschaftung, wirtschaftliche Entwicklung oder Biodiversitätserhaltung profitieren oder verlieren und bietet wichtige Informationen für zukünftige Priorisierungen in der Landnutzung.

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Chapter One
SYNOPSIS

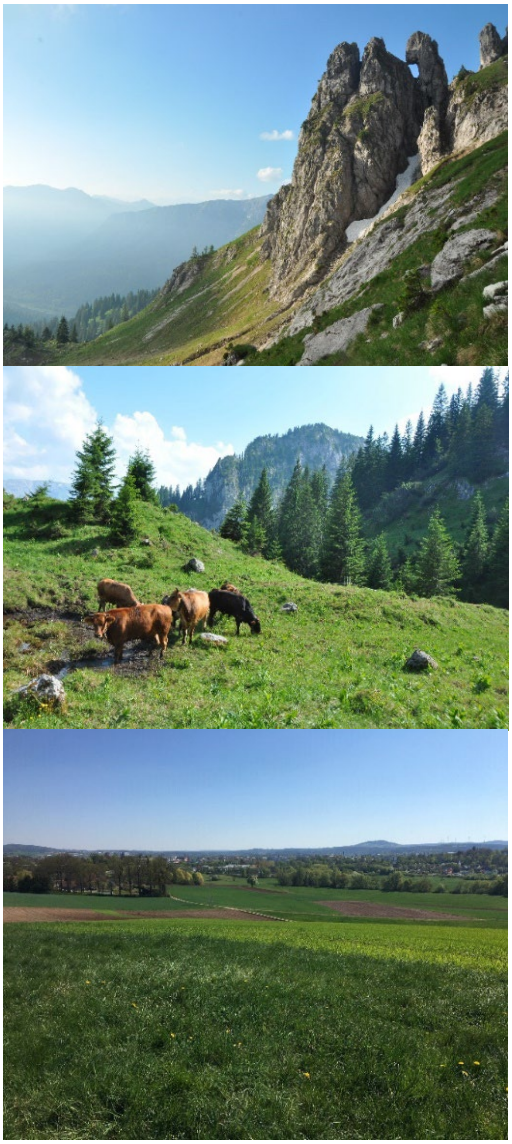
1.1 Introduction

1.1.1 Ecosystem services of (pre-)Alpine grasslands

Ecosystems provide various direct and indirect benefits to people, referred to as ecosystem services (MA 2005; see Box 1). However, climate change, decline in biodiversity, and deterioration of ecosystems impact the capacity of nature to provide such services globally. While there is a continuing rise in provisioning services such as food and energy production, this is at the expense of natures' ability to provide these services in the future. This frequently also limits the supply of other ecosystem services. The development is primarily driven by human decision-making, but inadvertently carries a negative impact on many peoples' quality of life (IPBES, 2019). As trade-offs of ecosystem services can occur spatially distant (e.g., downstream) or temporally postponed, negative impacts are often unequally distributed among different actors.

In highly commodified western agricultural landscapes, there is a strong focus towards food and feed production, with corresponding decreases in ecosystem services such as water quality regulation, carbon sequestration, or habitat for biodiversity (IPBES, 2018). A prominent type of agricultural land use in Europe are permanent grasslands, which are present on 17% of the terrestrial surface and comprise >30% of the agricultural land area in the European Union (Eurostat, 2022). Different types of permanent grasslands can be broadly categorized as natural, semi-natural, and improved grasslands (Bengtsson et al., 2019; see Box 1). In Europe, semi-natural and improved grasslands have been maintained by cutting (meadows) and grazing (pastures) for centuries, serving as the basis for livestock production (Schils et al., 2022). The fodder and feed produced is highly relevant for farming as grass is considered among the least expensive, high-quality nutrient inputs for dairy and meat production systems (Cocca et al., 2012). Besides fodder production, grasslands provide a multitude of important regulating ecosystem services, such as carbon sequestration, water quality regulation, erosion control, flood control, and cultural ecosystem services such as recreation (Bengtsson et al., 2019; Zhao et al., 2020). In a literature review, Schils et al. (2022) determined that preventing grasslands conversion into other land uses favors the multifunctionality of the landscapes. Compared to croplands, grasslands supply the most ecosystem services. In light of the more numerous benefits of grasslands, only the quantity and quality of fodder production are higher in croplands. Compared to forests, biodiversity and cultural services are generally higher in grasslands. Among grasslands, the provisioning of ecosystem services strongly depends on the

management regime (cutting or grazing) and intensity (e.g., fertilization), as well as environmental and climatic factors (Le Clec'h et al., 2019; Zhao et al., 2020). Generally, increasing management intensity by means of higher nitrogen input, increasing cut frequencies, and grass renewal provide higher fodder production. Simultaneously, this decreases the supply of other ecosystem services of grasslands in terms of regulating ecosystem services such as water purification or climate regulation (Schils et al., 2022). Increasing management intensities are also highly problematic, as extensively managed grasslands are specifically considered to be hotspots of biodiversity (Habel et al., 2013). With increased management intensities in the last century aiming to produce more agricultural output, large areas of permanent grasslands have been lost or subjected to more intensive management (Schils et al., 2022). Particularly in Alpine areas, extensively used seasonal pastures face abandonment, while intensively used meadows and pastures in the valleys are prone to even more intensive management in order to yield high fodder and feed (Cocca et al., 2012; Monteiro et al., 2011; Schirpke et al., 2019).



Photos: T.M.Schmitt

Figure 1. Illustration of different types of grasslands in the study areas: natural grasslands (top); semi-natural grasslands (center); improved grasslands (bottom).

1.1.2 Importance of ecosystem services to people

An essential driver of the loss of ecosystem services in agricultural landscapes is the unsustainable use of land. It is well established that the values people hold towards nature and ecosystem services are related to peoples' behavior and can help to understand the actions people take (Harmáčková et al., 2021; Kaiser et al., 1999). Different stakeholders can have varying expectations concerning which ecosystem services should be prioritized in a landscape. At the same time, power relationships among stakeholders can influence who has access to, can use and manage ecosystem services. This contributes to the emergence of potential winners and losers, which can lead to conflicts between stakeholders, making a case for the valuation of

ecosystem services (Daw et al., 2015; Howe et al., 2014; Zoderer et al., 2019).

Besides the relative importance of ecosystem services, people often have different views concerning specific ecosystem services as they relate to their uses or interests (Anderson et al., 2022; Lamarque et al., 2011). Methods, concepts, and theories that aim to categorize human-environment relationships are manifold, based on different disciplines, and have been around for decades (Stålhammar and Thorén, 2019). These include attitudes to (e.g., Poppenborg and Koellner, 2013), preferences (Koellner et al., 2010; Martín-López et al., 2012), (perceived) values (Arias-Arévalo et al., 2017; Sherrouse et al., 2011), or perceptions. Although these concepts are based on different methodologies, they all relate to behavior and decision-making (Bennett, 2016). Bennett (2016) argues that perceptions can be more loosely defined than the other concepts mentioned above and define them as a way of observation, understanding, interpretation, and evaluation. Similarly, the term value can broadly be defined as "the importance, worth, or usefulness" to people (Díaz et al., 2015).

People perceive, experience, and interact with nature in diverse ways, leading to different understandings on nature's role in one's lives. Consequently, the types of values associated with nature and ecosystem services are manifold. In the Values Assessment of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), Anderson et al. (2022) conceptualize that different worldviews ultimately underly the diverging values that people hold towards nature and ecosystem services. Worldviews influence the understanding and interactions of people with nature and are shaped by cultural backgrounds, knowledge systems, and languages. Life goals or guiding principles, called broad values, are influenced by one's worldviews. Examples of broad values include living in harmony with nature or the pursuit of prosperity, and are relatively stable across peoples' lives. More explicitly, specific values of nature and ecosystem services "are opinions or judgments of the importance of specific things in particular situations and contexts" (Anderson et al., 2022). In literature prior to the methodological assessment of the valuation of values by Anderson et al. (2022), specific values have also been referred to as assigned values, contextual values, or importance. Instrumental, intrinsic, and relational values of ecosystem services and nature can be considered to be specific values, which can change over time depending on individual, social, and socio-ecological processes (Anderson et al., 2022; see Box 1).

1.1.3 Plural valuation of nature and ecosystem services

To date, agricultural management is frequently guided by political and economic decisions based on only a small set of marked-based, instrumental values (IPBES, 2022). An apple tree,

for example, can be valued "as a means to achieve a certain amount and quality of apples." This is considered an instrumental value as the same number of apples may replace the fruits with similar quality purchased in a supermarket. The relationship of the farmer with the apple tree or orchard, however, may go beyond this substitutable, economic means to an end (Martín-López, 2021). Besides instrumental values, intrinsic values of nature are defined as an end themselves, and are independent of any human experience (Díaz et al., 2015; O'Connor and Kenter, 2019). As an "objective" intrinsic value is considered independent of any human valuation, this dissertation applies the concept of "subjective" intrinsic value based on the idea that humans can express regard for biodiversity and ecosystem services independent of human interest (Díaz et al., 2015; Kenter and O'Connor, 2022; see Box 1). Before 2016, past debates on ecosystem services and environmental protection mainly focused on these two specific value categories (IPBES, 2022). In recent years, the literature has manifested that the standalone consideration of instrumental and intrinsic values fails to integrate views on personal and collective well-being with regard to nature and the environment (Chan et al., 2016). This is critically important, as few decisions are made on the merit of basing a decision axis on "how things possess inherent worth" (intrinsic value) or "satisfy their preferences" (instrumental values). It is a growing consensus that people further consider how they relate with nature and others, leading to the emergence of relational values (Chan et al., 2016; IPBES, 2022). Initial studies have identified relational values in different contexts and pointed to their relevance to guide policies and land management decisions (e.g., Arias-Arévalo et al., 2017; Chapman, 2019; Riechers et al., 2020; Topp et al., 2021). Including relational values in policy- and environmental decision-making can increase the participation of different stakeholders (Jax et al., 2018) and can lead to more just, equitable, and sustainable land use (Anderson et al., 2022). Particularly, indigenous communities benefit from including relational values in policy-making (Anderson et al., 2022; Himes and Muraca, 2018). In European agricultural contexts, Chapman (2019) stressed that including the relational values of farmers in agri-environmental policies can lead to a more substantial uptake of the schemes and a more successful implementation of associated conservation strategies.

Relational values have emerged with the evolution of nature's contributions to people, opening the concept of ecosystem services to more pluralistic valuation approaches (Kenter and O'Connor, 2022). Nevertheless, this dissertation uses the term ecosystem services to align with the great extent of previous research on the topic, in order to promote ease of science communication to local stakeholders and policies (aligning with the terminology used in Germany language), and for consistency within the research project that has started before the

agreement of IPBES to adjust the terminology from ecosystem services to nature's contributions to people. Due to the similarities in the terminology definitions (Box 1), we use the term ecosystem services but frequently refer to aspects that have evolved with the emergence of nature's contributions to people, such as relational values.

When acknowledging the plurality of values associated with landscape and nature, assessing grasslands and their ecosystem services regarding people's various, non-substitutable relationships with the ecosystem is crucial. Grasslands provide a large number of ecosystem services to people and are considered to be "more important for ecosystem services than you may think" (Bengtsson et al., 2019). They are considered a hotspot for biodiversity (Habel et al., 2013) and serve as a dominant aspect of the cultural landscape. Hence, this thesis contributes to the literature on linking plural valuation in a case study of grasslands based on the following research gaps.

1.1.4 Research gaps

Despite their high importance, the ecosystem services of grasslands are highly understudied compared to ecosystem services in other ecosystems (Bengtsson et al., 2019). Specifically, there is a profound gap concerning knowledge of the socio-economic aspects of grassland ecosystem services (Zhao et al., 2020). The methodological assessment on the valuation of nature by IPBES (2022) found in an extensive review of 79 000 studies that only 7% of studies conducting valuation were based on grasslands. As "the means determine the end", it is essential to note that methodologies used to undertake valuation influence the outcome (Jacobs et al., 2018). Hence, integrating different methodologies, indicators, and data is essential to gain realistic insights into human-environment relationships in the form of values associated by people with nature. In grassland ecosystem services, Zhao et al. (2020) determined a lack and need for studies combining different kinds of data and analytical techniques.

Valuation of nature and ecosystem services had been predominantly based on economic methods. Although a substantial increase in socio-cultural analyses has been observed in recent years, there is still a gap in understanding the socio-cultural values of ecosystem services. To date, 50% of value indicators are biophysical, 26% monetary, and only 21% socio-cultural (IPBES, 2022). In a recent review, Walz et al. (2019) unravelled that while socio-cultural studies that investigate perceptions of ecosystem services have increased in number, there is a specific need to investigate combinations of active stakeholders that manage the land (e.g., farmers) and passive stakeholders who either benefit or suffer the costs from changes in ecosystem services delivery (e.g., citizens). Considering both plays a key role when prioritizing

management practices (Turkelboom et al., 2018). As there can also be significant differences within stakeholder groups, it is vital to consider the heterogeneity within stakeholders' groups, which is included in a few studies only (Tauro et al., 2018).

Beyond assessing perceptions and importance of ecosystem services, investigating relational values can give additional insights for managing landscapes (Riechers et al., 2020), and can help to further understand the multiple, non-substitutable aspects that people value about nature. According to an in-depth review of IPBES (2022), 74% of the values assessed in studies were based on instrumental values, 20% on intrinsic values, and only 6% on the studies on relational values. This shows that the plural valuation of nature and ecosystem services is still in its infancy and outlines the need for a research focus integrating the study of relational values. Moreover, further work on the linkages between socio-demographic drivers and relational values and specifically combining them through quantitative methods are still missing for a better conceptual and methodological application of relational values. Spatial analysis of ecosystem services and valuation are prominent tools for advising decision-making (e.g., Fagerholm et al., 2019; Sherrouse et al., 2011) and can be crucial for landscape management (De Vreese et al., 2016); however, only few studies link plural valuation with participatory mapping.

Besides investigating the perceived importance of ecosystem services, it is necessary to link them to the actual supply of ecosystem services through their synergies and trade-offs (Bennett et al., 2009; Lamarque et al., 2011). Previous studies have often overlooked the potential for conflicts, which can be unraveled when identifying both the biophysical aspects and the importance of economic demand (Bengtsson et al., 2019; Cord et al., 2017; Zoderer et al., 2019). It is specifically relevant to further investigate the role of recreation with other ecosystem services in grasslands since previous studies have identified diverse relationships between recreation and fodder production (e.g., Le Clec'h et al., 2019). In this dissertation, the studies on socio-cultural valuation (Paper 1 and 2) have identified recreation as an essential ecosystem service and relational value. However, recreation could also not be explained by social characteristics of the respondents, illustrating the need to further study the role of recreation on grasslands.

1.1.5 Goals of the dissertation

To address the outlined research gaps, this dissertation investigates the socio-cultural importance and field-specific supply of ecosystem services supplied by Alpine and Pre-Alpine grasslands. The individual studies aimed to answer the following research questions:

i) How do perceptions of ecosystem services differ between farmers and citizens, specifically between the perceived suitability of grasslands to supply ecosystem services (citizens) and the perceived importance of ecosystem services in grassland management decisions (farmers)?
ii) What are the specific values of grasslands, how are they related to perceptions of ecosystem services and social characteristics of respondents, and how are they distributed spatially?
iii) What are the synergies and trade-offs of the field-specific supply of ecosystem services and the relationships of the ecosystem services with farm management-related variables, policies, environmental, and infrastructural variables?

Based on the results of the individual papers (Chapter 2), the synthesis of this cumulative dissertation discusses the overlaps of trade-offs in ecosystem services supply with differences in the socio-cultural valuation. Also, relational values and cultural ecosystem services are discussed regarding their implications for management and policy.

Box 1 Definitions and descriptions of important concepts and terms used in this dissertation.

Values: Multiple ways in which nature, ecosystems, or ecosystem services are important for individuals or social groups; the importance, worth or usefulness (Díaz et al., 2015)

Plural valuation of ecosystems: The process of analyzing, assessing, or understanding the multiple ways in which ecosystems and ecosystem services are important for people and how these multiple ways of importance are related (e.g., coexistences, synergies, trade-offs) (Arias-Arévalo et al., 2017).

Specific values: opinions or judgements of the importance of specific things in particular situations and contexts or states of affairs; also referred to as assigned values, contextual values, importance, or value domains (Anderson et al., 2022; Arias-Arévalo et al., 2017).

- *Instrumental value:* The value of an entity as merely a means to an end (Arias-Arévalo et al., 2017).
- *Intrinsic value*: The value of nature, ecosystems, or life as an ends in themselves, irrespective of their utility to humans (Arias-Arévalo et al., 2017). This dissertation refers to "subjective" intrinsic values when describing intrinsic values.
- *Relational value*: The importance attributed to meaningful relations and responsibilities between humans and between humans and nature (Arias-Arévalo et al., 2017).

Perceptions: a way of observation, understanding, interpretation, and evaluation (Bennett, 2016).

Ecosystem services: The benefits people obtain from ecosystems (MA, 2005). Ecosystem services can be categorized based on different concepts. In this study, we base the categorization on Rabe et al. (2016) that includes provisioning services (e.g., fodder production), regulating services (e.g., soil erosion reduction), and cultural services (e.g., recreation).

Natures' contributions to people: Are all the contributions of living nature (i.e. diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to the quality of life for people (IPBES, 2019).

Natural grasslands: natural areas mainly created by processes related to climate, fire, and wildlife grazing, but can also be used by livestock (Bengtsson et al., 2019).

Semi-natural grasslands: product of human management, require livestock grazing or hay cutting for their maintenance, and will generally be encroached by shrubs and trees if taken out of production (Bengtsson et al., 2019).

Improved grasslands: result from plowing and sowing agricultural varieties or non-native grasses with high production potential; they are artificially fertilized and maintained by intensive management (Bengtsson et al., 2019).

1.2 Methods

1.2.1 Study area

This study was conducted in Bavaria, Germany. It was located in a grassland-dominated pre-Alpine and Alpine environment based on the catchment of the river Ammer. A secondary study area was used in addition in Paper 2, namely the Red and White Main study area (Fig. 2).

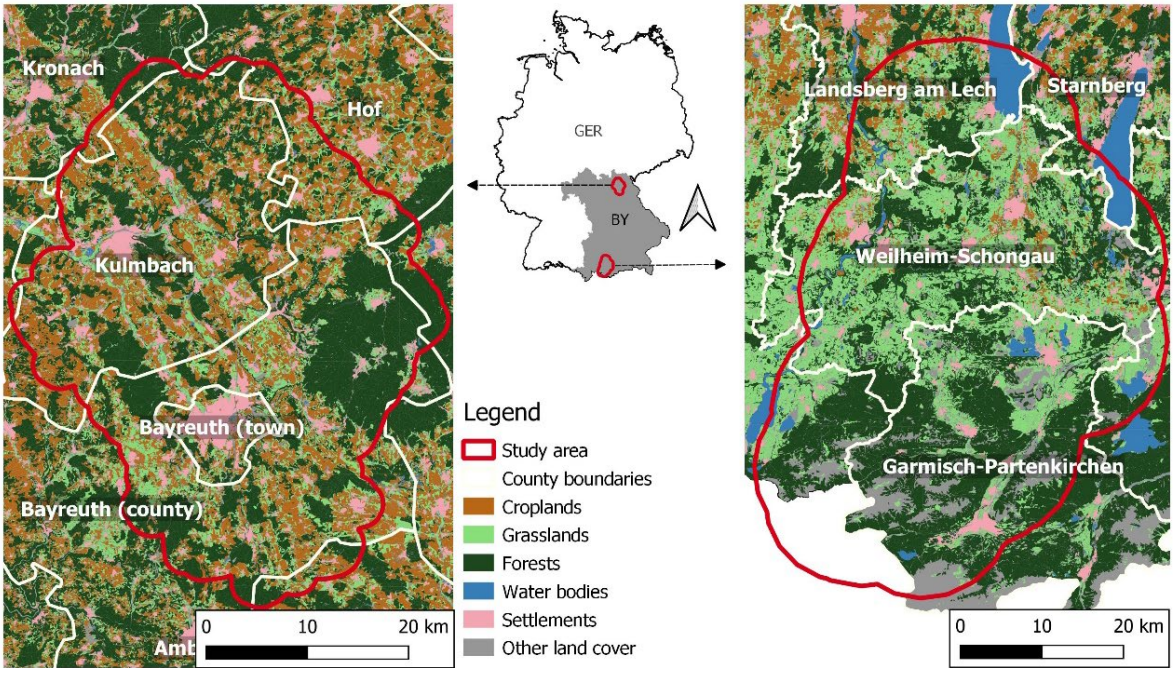


Figure 2. Location and land use of the Red and White Main (left) and Ammer (right) study areas in Bavaria, Germany. (Data: LDBV, 2016)

The Ammer study area is characterized by a hilly, pre-Alpine landscape in the north (average of 881 m.a.s.l.) and Alpine mountains in the south, which consist of parts of the Wetterstein mountains, Ammergau Alps, and Bavarian Prealps. It includes Germany's highest peak, "Zugspitze," with an altitude of 2,969 m.a.s.l (NASA, 2009). The Ammer study area consists of agricultural land (36%), forests (41%), lakes (5%), and settlements (4%). Other land covers (14%) include mountainous rock and peat environments (LDBV, 2016). The agricultural land use of the study area is mainly composed of grasslands (71%), but management differs throughout the study area. In the northern, pre-Alpine part, there is proportionally more intensive management, while in the southern part, grasslands are frequently managed less intensively. The northern part has a grassland share of close to 50%. In contrast, the southern part's agricultural land has a grassland share of 99% (LfStat, 2017). Grasslands in the southern part include traditional humpback meadows (Buckelwiesen), bedding meadows, and Alpine pastures. In the southern part of study area, the Ammergau Alps Natural Park is located. Structural change in the study area originates from many small-scale farmers being taken over

by larger agricultural farms or expanding the agricultural businesses towards touristic use. In the mountainous part, traditional land use practices such as transhumance and Alpine pastures have declined due to a lack of profitability and disproportional labor costs, leading to intensifying grassland management in the valleys. The strong presence of other land covers (e.g., peatlands and rocks) and the high stake of grasslands in the study area are special cases compared to the Bavarian average (Table 1).

A secondary study area was located in northern Bavaria based on the catchment of the Red and White Main. It was used in Paper 2 to compare the specific values attributed to grasslands in the Ammer study area with a study area of more mixed agricultural land-use. Contrasting to the Ammer study area, the Red and White Main study area is characterized by mid-altitude mountain ranges, including the Fichtel Mountains, Franconian Switzerland, and the Franconian Forest, also classified as Nature Parks (IUCN category V). The highest peak of Northern Bavaria, "Schneeberg" (1051 m.a.s.l.), is in the Fichtel Mountains. The agricultural land use of the Red and White Main study area is more mixed than that of the Ammer study area and is more comparable with the Bavarian average (Table 1).

Table 1 Land use proportions in the study areas compared to the average in Bavaria, Germany. (Sources: LDBV, 2016)

Land use	Bavarian average	Ammer study area	Red and White Main study area
Agricultural land	47%	36%	41%
… thereof grassland	34%	71%	40%
Forests	35%	41%	42%
Settlements	12%	5%	7%
Other	6%	18%	10%

1.2.2. Data acquisition

The primary data source of this dissertation was retrieved by conducting surveys in the study areas. For analyzing synergies and trade-offs of ecosystem services supply, secondary data was used in Paper 3. To study the importance of grassland ecosystem services, farmers and citizens in the study areas were invited to fill out a questionnaire themed "Agriculture, Climate Change, and Nature Conservation" using the same sampling techniques in 2018 and 2020. Members of the research team approached farmers at the regional offices of Nutrition, Agriculture, and

Forestry (AELF) to fill out the questionnaire (Fig. 3; red star). To invite citizens to complete the questionnaire at home, 79,313 households in a 3 km radius surrounding 20 randomly selected points received postcards with a link and QR-code to participate in the research. Locations were randomly selected (red dots) but manually adjusted to be in areas of higher population density, creating the final locations of centroids (black dots). Black circles illustrate

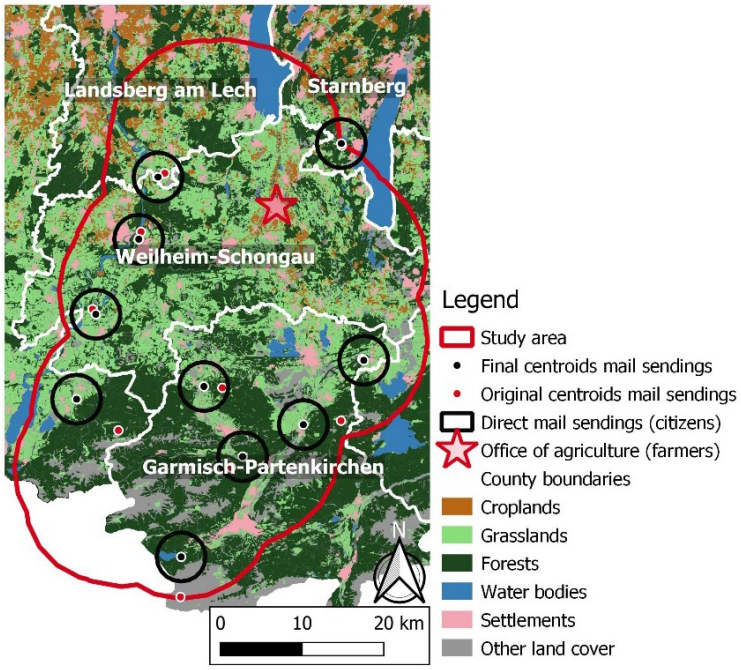


Figure 3. Locations of survey collection in the Ammer study area. See Supporting Information of Paper 2 for the locations of survey collection in the secondary study area of the Red and White Main. (Data: LDBV, 2016)

the final regions where households received a postcard via direct mail (see Fig. 3).

The surveys included a 5-point Likert question to identify the actors' importance of a set of ecosystem services used in Paper 1 and 2. The ecosystem services assessed were selected based on expert knowledge and included fodder production, animal production, energy plant production, soil fertility, groundwater quality, climate regulation, soil erosion reduction, flood risk reduction, pollination, biological pest control, and recreation. A question on where and why the actors perceived specific grasslands to be especially valuable was analyzed in Paper 2. Furthermore, results in Paper 1 and 2 are based on survey questions on knowledge of the ecosystem services concept, social characteristics, environmental attitudes, and farm characteristics. Social characteristics included questions on socio-economic (e.g., employment) and socio-demographic (e.g., age, gender) variables. The questions can be found in the Supporting Information of Paper 1 and 2.

To study synergies and trade-offs between the actual supply of ecosystem services in grasslands, a set of different data acquisition techniques was used. To approximate yield, remotely sensed number of cuts on each grassland parcel was the basis. Photo-User-Days

calculated from metadata of crowdsourced photographs downloaded from Flickr served as an indicator for recreation. Furthermore, agri-environmental payments were used as an indicator for habitat and regulating ecosystem services (see Paper 3).

Table 2 Survey respondents in 2018 and 2020 in both study areas. Additional respondents answered the survey, but did not indicate a study area.

	Ammer study area	Red and White Main study area	Additional respondents
Farmers 2018	358 [1]	188	-
Citizens 2018	251 [1,2]	209 [2]	66 [2]
Farmers 2020	122	191	-
Citizens 2020	196 [2]	240 [2]	176 [2]

[1] Sample used in Paper 1; [2] Sample used in Paper 2

1.2.3 Data analysis

Besides different kinds of data acquisition, this dissertation used a variety of analysis techniques. These included descriptive analyses, qualitative and quantitative statistical analyses, and geo-spatial techniques (Table 2). Some methods originated from ecological sciences (e.g., Redundancy Analysis), others are based on social sciences (e.g., surveys), but all methods have been previously used for answering similar research questions and have been successfully applied in socio-ecological research (Biggs et al., 2021). R Studio was used for preparation of data and the statistical analyses. MaxQDA Plus was used to categorize qualitative data, ArcGIS, and QGIS for spatial data preparation and analyses. Table 3 gives an overview of the analysis techniques used in each paper.

Qualitative data analyses

Qualitative methods investigating the content of statements articulated by people are used in socio-ecological research to disentangle characteristics of language, its underlying themes, and meanings that emerge. These analyses can be conducted inductively (researcher searches for themes in the data) or deductively (research is based on previously developed themes originating from theory) (Biggs et al., 2021; Mayring, 2015). In Paper 2, a thematic analysis of text was used to investigate the open verbatims of citizens referring to the reasons why they specifically value certain grasslands using an inductive-deductive approach. While initial

categories of specific values were taken from literature (Arias-Arévalo et al., 2018, 2017; Topp et al., 2021), those were adjusted to fit the context of (pre-)Alpine grassland ecosystems. The statements that were categorized into specific values were then coded as nominal occurrence data and could be further analyzed with quantitative methods.

Quantitative data analyses

Descriptive statistics summarize a given dataset and give initial insights into the data (Biggs et al., 2021). In this dissertation, descriptive statistics were used in Paper 1 and 2 to retrieve a general idea about the distribution of perceptions and values. In Paper 3, correlations of ecosystem service supply were conducted.

Difference tests can be applied to compare whether there are differences in mean or median between two or more groups (Field et al., 2012). We applied non-parametric tests suitable for ordinal data to assess matches and mismatches in the Likert-based perceptions of ecosystem services, specifically Mann-Whitney U (2 groups) and Kruskal-Wallis Test (3 groups).

Multivariate ordination techniques originated in ecology to relate a matrix of multiple species' occurrences with a matrix of predictor variables (Biggs et al., 2021). Similarly, these techniques have been successfully applied in socio-ecological studies to relate (perceptions of) ecosystem services to potential (social) predictor variables (Casado-Arzuaga et al., 2013; Morales-Reyes et al., 2018). We employed Redundancy Analysis - a variation of a Principal component analysis that is commonly used for a continuous response matrix - to link social predictors to 5- Point Likert-based perceptions of ecosystem services (Paper 1). Redundancy Analyses were also used to link grassland management variables to the supply of ecosystem services (Paper 3). Canonical Correspondence Analysis, on the other hand, uses a categorial response matrix. We employed this analysis technique in Paper 2 to link social predictors and 5-Point Likert based perceptions of ecosystem services to the occurrence of specific values. Monte Carlo Permutation tests were used to investigate the statistical significance of the models.

Paper 1 further included a model of clustering and dimension reduction consisting of a Principal Component Analysis followed by k-Means clustering to investigate heterogeneity within the actors of farmers and citizens. This technique was chosen as it is suitable for mixed variables consisting of categorical and numerical data (Vichi et al., 2019). In Paper 2, a hierarchical cluster analysis was conducted to group sub-types of relational values into clusters.

In Paper 3, a regression was conducted to understand variables that influence recreational activities on grasslands. Due to the strongly right-skewed data with a high number of zeros (grasslands with no photos taken on), a hurdle regression model was used.

Spatial analyses

The distribution of yield supply and agri-environmental payments throughout the study area was visually analyzed with a bivariate map. Additionally, the distribution of recreation was analyzed with kernel density for presence/absence data and Getis-Ord Gi* statistics to investigate hotspots of high numbers of recreation on grasslands (Paper 3). Getis-Ord Gi* statistics also revealed hotspots and coldspots of specific values in Paper 2. The hotspots represent a spatial cluster of points associated with the respective values more frequently than by random choice within the context of neighboring points. In this case, hotspots are defined as areas where a particular variable is significantly higher than average (Getis and Ord, 1992).

Table 3 Data types used and analyses conducted in each study of the dissertation. ES = Ecosystem service; Quant. = Quantitative; Qual. = Qualitative.

	Study goals	Data types			Data analysis
		Quant.	Qual.	Spatial	
Paper 1	Heterogeneity among farmers and citizens	x			Clustering and Dimension Reduction
	(Mis-)matches ES perceptions between and among farmers and citizens	x			Mann-Whitney U Test / Kruskall Wallis Test
	Relationship ES perceptions and farm type/social characteristics	x			Redundancy Analysis
Paper 2	Elicit specific values of grasslands (instrumental, intrinsic, and relational values)		x		Qualitative Content Analysis
	Spatial distribution: trade-offs and synergies between the values			x	Getis-Ord Gi* Hot-/coldspot analysis
	Relationship ES perceptions, specific values, social characteristics	x			Canonical Correspondence Analysis
Paper 3	Assess the supply of ecosystem services on a plot level	x			Redundancy Analysis
	Investigate the association of environmental, infrastructural, and farm management variables on recreation	x			Hurdle Regression
	Spatial distribution of ES supply			x	Getis-Ord Gi* Hotspot analysis; Kernel density plots

1.3. Synthesis of Results

Over the course of three manuscripts, this dissertation investigated the importance of pre-Alpine and Alpine grasslands to people. The following synthesis discusses the results of the individual papers by showing that the different values of grasslands, indicated by stakeholders, can be linked to the actual trade-offs in the supply of ecosystem services. The synthesis of the results further investigates the role of relational values in understanding human-environment interactions in grasslands and provides several implications for management, policy, and future research.

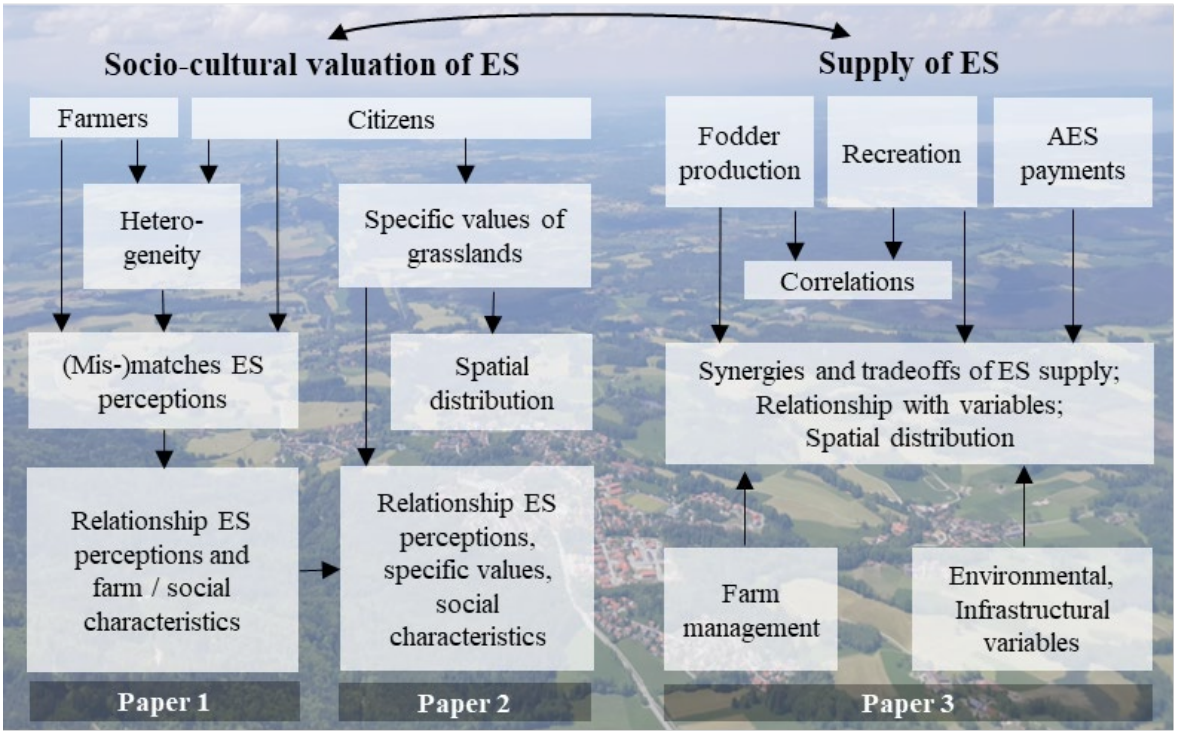


Figure 4. Overview of the contribution of the individual studies to the synopsis of the dissertation. ES = Ecosystem services; AES = Agri-environmental schemes.

The following discussion synthesizes the results of three individual papers. The individual papers revealed the following key results that are described in detail in Chapter 2:

i) Grasslands are perceived to be highly important to farmers and citizens, not only for agricultural production but for most ecosystem services assessed. Still, significant mismatches occurred between the actors, for instance regarding fodder production and recreation. The perceived importance of ecosystem services and specific values of grasslands are also strongly influenced by the social characteristics of the respondents (see Paper 1).

ii) While grasslands are important for both economic utility (instrumental values) and biodiversity conservation (intrinsic values), verbatims concerning the importance of grasslands resonated most frequently with relational values (e.g., recreation, care, or sense of place). Relational values showed the multitude of non-substitutable relationships that people have with grasslands. Trade-offs occurred primarily between instrumental and intrinsic values (see Paper 2).

iii) Analyzing the supply of ecosystem services revealed clear trade-offs between fodder production on the one hand and habitat / regulating ecosystem services on the other hand. Also, a weak but significant negative relationship between fodder production and recreation was found. Recreation, specifically, was co-produced by environmental and infrastructural variables (see Paper 3).

1.3.1 Importance of (pre-)Alpine grassland for farmers and citizens

This dissertation emphasizes the importance of grasslands for the well-being of people. Besides the high importance that both farmers and citizens placed on fodder production, the primary agricultural output of grasslands, the study points to the importance of often neglected ecosystem services.

Paper 1 showed an overall high importance of grassland ecosystem services as perceived by both citizens and farmers. Out of eleven ecosystem services assessed, only the production of energy plants was not perceived to be important. Farmers, specifically, indicated low importance on energy plant production in their management decisions. This illustrates the sampled farmers' importance in producing agricultural goods and not merely economic income (Dietze et al., 2019). The other ecosystem services assessed – provisioning (fodder production, animal production in open fields), regulating (soil fertility, groundwater quality, climate regulation, soil erosion reduction, flood risk reduction, pollination, biological pest control), and cultural (recreation) – were identified to be important in the management decisions of farmers. Citizens also perceived these ecosystem services as suitable to be supplied by grasslands

The overall high importance of ecosystem services supplied by grasslands, as studied in Paper 1, is in line with findings on the perceptions of ecosystem services in agricultural environments in previous studies (Bernués et al., 2013; Howley, 2014; Pachoud et al., 2020). It also links to the plurality of values associated with grassland found in Paper 2. The respondents referred to a wide range of specific values regarding grasslands, spanning from instrumental (5.3%) to intrinsic (32.2%) and relational values (62.5%). Relational values were highly diverse and included sub-types security, ecological resilience, mental and physical health, sense of

place, cultural heritage, aesthetics, recreation, cognitive development, care, social relations, altruism, and meaningful occupations. This illustrates the high importance of grasslands to people beyond economic utility for various non-substitutable reasons.

Paper 1 and 2 showed that grasslands are highly important to people. Notably, cultural ecosystem services and relational values like recreation were of high importance to citizens. However, recreation was centered in the middle of the major explanatory axis of the Redundancy Analysis (Paper 1) and Canonical Correspondence Analysis (Paper 2), showing the need for further investigating the underlying factors of recreation. Thus, in Paper 3, we studied the contribution of grasslands to recreation. Grasslands, which are an essential component of the cultural landscape in the study area, co-produced recreational ecosystem services in combination with cultural, natural, and infrastructural factors. We found significantly higher visitation rates in areas with a high grassland share in the agricultural land use than in areas with proportionally more croplands in the share of agricultural land, which illustrates the importance of grasslands for recreational activities.

1.3.2 Trade-offs in ecosystem services supply overlap with conflicting values of stakeholders

The results of the individual studies unraveled a link between stakeholders' conflicting socio-cultural values of ecosystem services and actual trade-offs in their supply. This is particularly relevant, as differing landscape priorities associated with trade-offs in the supply of ecosystem services can lead to conflicts between stakeholders (Bennett, 2016; de Groot, 2006; Lamarque et al., 2011). These diverging priorities are especially relevant for grasslands, as management decisions play a decisive role regarding the supply of ecosystem services (Le Clec'h et al., 2019; Schils et al., 2022; Zhao et al., 2020).

In Paper 1, we identified fodder production, the primary agricultural output of grasslands, as the most important ecosystem service to farmers. Fodder production represented a significant mismatch in the perceptions between farmers and citizens. As farmers make their living from fodder production, the higher importance placed on this ecosystem service by farmers compared to citizens highlighted the importance of land managers to generate economic output from the production of food (Bidegain et al., 2019; Howley, 2014; Zoderer et al., 2019). Other mismatches that emerged between farmers and citizens include soil fertility, flood risk reduction, and recreation (Paper 1 Fig. 2). Soil fertility, a regulating ecosystem service that is strongly linked to potential yield, was also positively associated with marketed services such as forage production in previous studies (e.g., Lamarque et al., 2011). Overall, the differences in perceptions between citizens and farmers revealed in Paper 1 are mainly in line with studies on

ecosystem service perceptions in other (semi-) natural contexts (e.g., Bernués et al., 2013). When considering the heterogeneity among farmers and citizens, we also found trade-offs in the perceived importance of ecosystem services between fodder production and other ecosystem services (Paper 1). We identified two clusters of farmers and three clusters of citizens in our study area. This revealed that farmers who are male and higher educated are more strongly related to fodder production. Also, farmers belonging to the cluster of Farmers "Subalp", namely those farmers with larger farms, full-time farming, and location in the more intensively managed pre-Alpine part of the study area, were more strongly related to fodder production than farmers belonging to the cluster Farmers "Alp". This pattern persisted with citizens who are male and who are less engaged in environmental activities.

Correspondingly, in Paper 2, intrinsic values were attributed more frequently by respondents who were female, higher educated, and engaged in environmental activities. Citizens who perceived grasslands to be highly important for provisioning ecosystem services (fodder production, animal production) also attributed instrumental values to grasslands (Paper 2 Fig. 4). Intrinsic and instrumental values were found on the opposing sides of axis 1 in the CCA, illustrating a dichotomy between the specific values (Paper 2 Fig. 4). The relatively low instrumental values assigned to grasslands by citizens (5.3%) in Paper 2 link to the perceptions of grassland ecosystem services in Paper 1. Citizens indicated lower importance of grasslands for fodder production than farmers. Examples of verbatims associated with instrumental values given in Paper 2 included e.g., "*size of the area and proximity to consumers (2020302)" or "easily economically usable (location, field size) (2020286)"* linking perceptions of grasslands to be suitable to supply provisioning services to instrumental values.

Regarding the actual supply of ecosystem services, results of Paper 3 demonstrated trade-offs between fodder production, the primary agricultural output of grasslands, and habitat / regulating ecosystem services, estimated by agri-environmental payments. The agri-environmental payments substitute a loss of income from yield in favor of habitat and regulating ecosystem services. On a plot scale, the multivariate ordination found a strong relationship between grassland types and ecosystem service indicators. For instance, meadows that belong to farms holding dairy cows were related to higher yields (Paper 3 Fig. 4). In mountain valleys, meadows are continuously intensified (Cocca et al., 2012; Monteiro et al., 2011). One possible explanation for intensive management is whether farms hold dairy cows or hold cattle merely for meat production, as indicated in a discussion by stakeholders at a participatory workshop in Garmisch-Partenkirchen in May 2022. This originates from the necessity of reaching higher and more nutrient-intense yields in farms that hold dairy cows, as these have to feed the higher

nutrient need of dairy cows than sole cattle farming for meat production. In the study area, fodder is likely to be mainly grass-based due to comparatively low milk yields and differs throughout the study area ranging from less than 6000 kg milk/year in the southern part to more than 7000 kg milk/year in the western and northern part of the study area (LfL, 2019). In higher elevations of the mountains, pastures have been the primary agricultural land use but increasingly face abandonment due to high labor and low productivity (Cocca et al., 2012). Those grasslands tend to be associated with higher agri-environmental payments.

The trade-offs between fodder production and other ecosystem services were also visible in the spatial distribution, both for ecosystem service supply (Paper 3) and socio-cultural values (Paper 2). Visually comparing the hotspots of specific values attributed to grasslands with locations of grasslands that supply certain ecosystem services revealed clear overlaps. High yield is supplied in the northern part of the study area and near the river Lech in the west (Paper 3 Fig. 3). These areas are located in counties with higher milk output per cow than those in the mountainous part. Specifically, the high yield outputs in the western part of the study area also overlap with hotspots of instrumental values of grasslands indicated by citizens (Paper 2 Fig. 3). On the other side, coldspots of instrumental values and hotspots of intrinsic values of grasslands were found around the Murnau peatlands, overlapping with areas of high agri-environmental payments substituting income from yield for habitat and regulating ecosystem services.

1.3.3 Relational values act as intermediary between instrumental and intrinsic values

In other contexts, Himes and Muraca (2018) and Klain et al. (2017) illustrated that relational values can function as an intermediary between intrinsic and instrumental values. In Paper 2, the results also showed that relational values of grasslands can act as a bridge between this dichotomy. Concerning the supply of ecosystem services, results of Paper 3 illustrated clear trade-offs between grasslands that were managed for provisioning services and grasslands managed for habitat / regulating ecosystem services, but recreation was present on all grassland types. This intermediate role of relational values and cultural ecosystem services indicates the importance of fostering human-environment relationships. This can contribute to overcoming potential conflicts associated with trade-offs of ecosystem services.

Values are not mutually exclusive and can be expressed simultaneously by one respondent (Arias-Arévalo et al., 2017; Himes and Muraca, 2018; IPBES, 2022). For instance, by expressing that grasslands are "*important for nature, recreation, and climate; dairy farming, milk, agriculture (2020304)*", one respondent simultaneously indicated instrumental, intrinsic,

and relational values of specific valuable grasslands. Throughout Paper 2, relational values such as sense of place, care, or recreation showed significant synergies with intrinsic and instrumental values.

A person's sense of place can be created through interactions with people and nature, creating a feeling of home and belonging. Such connections can contribute to fostering values of social cohesion and stewardship for nature (Martín-López, 2021; Masterson et al., 2017). In a study in northern Germany, Riechers et al. (2020) found that local agency can be key for the sustainable management of landscapes. In this dissertation, on a spatial scale, hotspots of grasslands valued for sense of place overlapped with instrumental value near the river Lech in the western part of the Ammer study area (Paper 2 Fig. 3). Also, on a personal scale, respondents who indicated instrumental values or sense of place as their reasons for valuing specific grasslands perceived them to be specifically suitable to supply provisioning ecosystem services such as fodder or animal production (Paper 2 Fig. 4). This indicates that utilitarian management of grasslands does not necessarily conflict with feelings of belonging and home, but both can actually nurture each other. Specifically, extensive grassland management is predominant in the Alpine part of the Ammer study area. However, the existence of grasslands shaping the landscape is threatened due to abandonment. This link can be illustrated by one respondent who indicated "*I am a farmer and an 'alpine herdsman' in the Ammer mountains and would like to continue to manage it as I always have. The mountains are so beautiful due to the management, so we do not need a change (2020335).*"

The maintenance of the seasonal summer pastures in the Ammer study area was also perceived to be very important for a set of ecosystem services in a study of visitors' and tourists' perspectives (von Heßberg et al., 2021). Recreation and tourism are important factors in the study area, which we also found to possess important relational value to foster human-environment relationships in (pre-)Alpine grassland landscapes. Respondents who indicated intrinsic values in their reasoning as to why they especially value certain grasslands also indicated that they frequently conduct private activities in nature, such as observing wild animals, collecting wild berries, or hiking (Paper 2). On a spatial scale, Paper 2 revealed overlaps between hotspots of intrinsic and recreational values. As values can nurture each other (Arias-Arévalo et al., 2018; Chan et al., 2016), such recreational activities can foster meaningful relationships with nature and a sense of care for nature. This can lead to an endorsement of moral rights and the recognition of intrinsic values (Martín-López, 2021).

By specifying why citizens perceive grasslands to be especially valuable, recreation was one of the most dominant relational values mentioned (Paper 2). However, recreation was one

of the mismatches between farmers' management considerations and citizens' perceived suitability, with higher importance for citizens than for farmers (Paper 1). This could be a source of potential conflict, as we found that citizens visit slightly more frequently extensively managed grassland over intensively managed ones (Paper 3). However, tourism is also an important form of income for farmers in the study area, particularly in the mountainous region characterized by part-time and more extensive farming. For instance, the Ammer Alps Nature Park is located in that area, which explicitly targets the conservation of nature by utilization through sustainable land use practices and recreational activities (Ammergauer Alpen GmbH, 2017). Farmers from this part of the study area also placed significantly higher importance on recreation in their management than farmers from the northern, pre-Alpine part (Paper 1).

Recreation on grassland was found to be especially high in the southern, Alpine part of the study area. This part of the study area is important for tourism, with a dominant touristic infrastructure, important cultural sites, and an appealing mountain environment. Studying Photo-User-Days on grasslands in Paper 3 unraveled that recreation on grassland is co-produced by the ecosystem, but also by other factors. For example, proximity to touristic features (e.g., castles), presence of infrastructural features (e.g., cable cars), and environmental characteristics (e.g., low share of croplands, distance to forests) were significantly correlated with the visitation of grasslands. This co-production of recreation is consistent with the only weak negative correlation between recreation and fodder provisioning that we found by comparing recreation on grasslands with field-specific yield supply. Hence, although extensively managed grasslands were visited more frequently, intensively managed grasslands also showed to be important for recreation. Hence. relational values such as recreation can serve as an important synergy with both high fodder production and high biodiversity. The results of the dissertation, thus, illustrated that relational value like sense of place, care, or recreation, can play a vital role for sustainable landscape management.

1.3.4 Plural valuation of grasslands and its implications for policy and management

The results of the studies illustrate the importance of carefully considering peoples' values of grasslands and grassland ecosystem services in land use planning, policies, and management decisions.

Due to several factors, such as urbanization, the rising use of electronic media and landscape simplification, relational values are continuously being substituted with instrumental values (Riechers et al., 2021; Soga and Gaston, 2016). This dissertation illustrated that grasslands provide an agricultural landscape that can foster the relationships necessary for the

conservation of nature and the maintenance of ecosystem services. As the erosion of relational values is associated with landscape simplification (Riechers et al., 2021), the results of this dissertation point to the importance of grasslands, particular extensively managed grasslands, for human-nature connectedness. As extensively managed grasslands are threatened by abandonment and intensification, the outcomes of this study suggest a further emphasis on targeting policies towards maintaining extensively managed grasslands. Fostering relational values on these grasslands is another compelling reason for this, beyond the high value of biodiversity and maintenance of ecosystem services.

The overlap of trade-offs between the supply of fodder production and habitat / regulating ecosystem with the socio-cultural values of (pre-)Alpine grasslands is important to acknowledge for landscape management and policy decisions. The identified trade-offs, particularly, might lead to conflicts between stakeholders and disagreements regarding landscape prioritization (Daw et al., 2015). Exemplarily, in 2019, a Bavarian-wide referendum on Biodiversity and Natural Beauty targeted several policies for more biodiversity-friendly agriculture (Hartmann et al., 2021). While citizens highly supported the referendum, there were strong disagreements among many farmers. Besides restrictions on management decisions, subsidies can be an important component of the policy-mix to maintain (extensively managed) grasslands. In a recent study, Chapman (2019) concluded that integrating farmers' relational values in conservation strategies can contribute to higher participation in the programs. Concerning seasonal Alpine summer pastures, a study on people visiting the area for recreation also revealed substantial agreement for subsidies and financial support to manage the highly extensively used summer pastures that are important for various ecosystem services and biodiversity (von Heßberg et al., 2021). The European Unions' Common Agricultural Policy further includes several payment schemes to protect ecosystem services of permanent grasslands (Schils et al., 2022). Besides purely agricultural policies, an application of the region to become UNESCO World Cultural Heritage might contribute to appreciating farmers' grassland management and support sustainable touristic and recreational activities. Indeed, fostering sustainable tourism and recreation can positively influence the maintenance of (extensively managed) grasslands (Cocca et al., 2012) as the benefits derived from recreation are closely linked to the positive experiences originating from relationships between people and nature (Havinga et al., 2021).

1.3.5 Limitations

This dissertation employed a mixed-methods approach to investigate the societal dimension of grasslands. Combining qualitative, quantitative, and spatial datasets and analytical techniques

proved to be very suitable for unraveling a link between peoples' socio-cultural values and the supply of ecosystem services. Nevertheless, this interdisciplinary approach entails several limitations regarding data acquisition and analysis.

The three individual studies (Chapter 2) were subject to limitations and assumptions concerning the acquired data, which are described in the limitation sections of the specific papers. As a major purpose of plural valuation is to recognize and include the voices of marginalized and less powerful people (Anderson et al., 2022; Martín-López, 2021; Zafra-Calvo et al., 2020), a sincere limitation of this dissertation is the representativity of the sample. In Paper 1 and 2, we acknowledge a bias in the sample of citizens respondents to the surveys, who were generally higher educated than the average citizen in Bavaria, Germany. Also, the questionnaire titled "Agriculture, climate change, and nature conservation" might have motivated respondents with a particular interest in this topic. Hence, citizens interested in the topic of nature conservation might be overrepresented in the sample. In Paper 3, several assumptions were taken regarding the calculation of the indicators of ecosystem services that limit the generalizability of the findings. Although Flickr is a frequently used website to obtain crowdsourced, geo-tagged photos and provides very good results for assessing recreation (Ghermandi, 2022; Levin et al., 2017), Flickr has been decreasingly used by the public in recent years and tended to be used by the younger, wealthier, and higher educated part of the population. This research is also subject to a certain subjectivity of the researcher. Specifically, in the Qualitative Content Analysis assigning values to categories, only certain objectivity was possible to be achieved (Paper 2). To keep the bias low, decisions regarding the value categorization were discussed by the authors of the study in several rounds of categorization.

The synthesis of the results of the individual studies, linking the relationship of ecosystem services supply with peoples' socio-cultural values, also needs to be interpreted carefully since spatial comparisons were conducted descriptively only. In Paper 2, the selection of valuable grasslands was conducted on a non-zoomable map. Also, the displayed size of circles to select areas of valuable grasslands differed depending on the electronic device that the citizens used for filling out the survey. On the contrary, in Paper 3, the spatial hotspots of ecosystem services were calculated based on field-specific data providing a detailed map. Further limitations of this study are that the Ammer study area has several specific characteristics, such as the types of grasslands present and their management regimes. Also, some major Bavarian tourist destinations are present in the study area and attract a disproportionally high number of visitors from all over the world. These include Castle Neuschwanstein, the UNESCO World Cultural Site Wieskirche, and Mount Zugspitze. As

socio-cultural valuation is frequently context-specific, extrapolating the results of this study to a broader context or region needs to be carefully considered.

1.3.6 Outlook

Conducting a study of interdisciplinary nature, constrained within the scope of a dissertation, inevitably leads to the emergence of future research needs.

The study entailed several limitations (see 1.3.5), which are subject to be addressed in future research. Predominantly, linking the supply of ecosystem services to associated values provided insights regarding implications of landscape management. Due to technical limitations, the link between supply and values in in the synthesis of this dissertations' results could only be assessed descriptively. It is suggested that additional research focuses to link the mapping of relational values with supply of ecosystem services and focuses its methodological approach along this research goal. To do so, it will be helpful to identify the values of grasslands and ecosystem services on a more detailed field scale. Taking this approach can also be interesting in other ecosystems and socio-ecological contexts. Future research should also target the data collected to be more representative of the population and potentially towards a larger study region. Coupling valuation approaches with modeling practices could be a useful continuation of this research, linking social processes with land use change modeling.

Participatory approaches are suggested for future research targeting similar research questions. Unfortunately, due to the Covid-19 pandemic, a participatory approach to valuation was very limited, making this dissertation strongly rely on survey results only. Nevertheless, during a modeling workshop conducted in May 2022 in Garmisch-Partenkirchen and in expert meetings at the Office of Nutrition, Agriculture, and Forestry (AELF) in Weilheim, we received valuable insights into stakeholders' values, perceived challenges for the future, and management decision-making processes. In future research, for instance, the Nature Futures' Framework of IPBES could be applied to couple results of this study with participatory scenario development. This could provide insights into possible pathways towards sustainable land-use scenarios (Pereira et al., 2020).

In addition to the limitations associated with using the platform Flickr to obtain Photo-User-Days, conducting further analyses on the content of texts and pictures is suggested in future research. For instance, using artificial intelligence or employing a standard protocol for assessing the content of crowd-sourced photos might allow for more profound insights into the relational values and cultural ecosystem services associated with grasslands.

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Chapter Two
PUBLICATIONS

PAPER I

Ecosystem services from (pre-)alpine grasslands: Matches and mismatches between citizens' perceived suitability and farmers' management considerations

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Ecosystem services from (pre-)Alpine grasslands: Matches and mismatches between citizens' perceived suitability and farmers' management considerations

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ABSTRACT

The integration of socio-cultural assessments in ecosystem services research has increased steadily over the last years. However, the stakeholders' perception of ecosystem services from grasslands, a major agricultural land cover in (pre-)Alpine landscapes, has received only limited attention. Furthermore, studying the heterogeneity of perceptions within stakeholder groups is a major scientific need. In this study, we examined the perceptions of farmers and citizens regarding grassland ecosystem services, specifically the matches and mismatches between perceived suitability of grasslands and importance assigned by farmers in their management considerations. We conducted surveys in a study area in southern Bavaria, Germany, in 2018. Overall, ecosystem services that citizens perceived as very suitable to be provided by grasslands aligned well with the ecosystem services that are highly important to farmers in their management considerations, but significant mismatches also existed among all categories of ecosystem services. Clustering and dimension reduction revealed two clusters of farmers and three clusters of citizens depending on farm characteristics and environmental attitudes, respectively. Redundancy analysis showed a strong influence of the stakeholder cluster on the perception of the services assessed. Furthermore, age and gender influenced the perceptions attached to grassland ecosystem services.

1. Introduction

Grassland ecosystems are widely distributed globally, covering almost a third of the world's terrestrial surface (Egoh et al., 2016). Grasslands of low management intensity are characterized as particular hotspots of biodiversity. Nevertheless, they are currently one of the most threatened ecosystems in Europe due to abandonment, afforestation, and transformation into crop fields (Habel et al., 2013). Apart from their conservation value due to high biodiversity, grasslands are imperative for a variety of ecosystem services. Ecosystem services supplied by grasslands range from provisioning (e.g., fodder production) to regulating (e.g., erosion control, maintenance of soil fertility) and cultural services (e.g., recreation) (Egoh et al., 2016; Bengtsson et al., 2019). To which degree each service is provided depends, among other reasons, on the management regime and intensity of the grasslands (Le Clec'h et al., 2019). Despite their high relevance, grasslands remain one of the most understudied ecosystems in ecosystem services research (Bengtsson et al., 2019). In recent years, grasslands have been part of some research on mountain agroecosystems from the supply side (e.g., Crouzat et al., 2015; Schirpke et al., 2016). On the demand side, few studies have addressed ecosystem services supplied by agroecosystems in mountains from the point of view of socio-cultural valuation (Martín-López et al., 2019). For example, Lamarque et al. (2011) explored the socio-cultural values of ecosystem services provided by grasslands in the Alps. Yet, most other studies on socio-cultural valuation of ecosystem services focused predominantly on cultural services (e.g., Schirpke et al., 2016; Junge et al., 2011) and, in the particular case of grasslands, socio-cultural valuation of ecosystem services is often part of broader research on mountain systems (e.g., Zoderer et al., 2016, 2019b). Our study aims to contribute to the existing literature by investigating

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perceptions of ecosystem services supplied by grasslands in both pre-mountainous and mountainous environments.

Diaz et al. (2015) define values broadly as the 'importance, worth or usefulness' of ecosystem services to people. Other studies are more distinct in the terminology and use attitudes to (e.g., Poppenborg and Koellner, 2013), preferences (e.g., Koellner et al., 2010; Martín-López et al., 2012), (perceived) values (e.g., Sherrouse et al., 2014; Klain et al., 2017; Arias-Arévalo et al., 2017), or perceptions (e.g., Iniesta-Arandia et al., 2014; Pachoud et al., 2020) of ecosystem services. The concepts are based on different methodologies, but all relate to behavior and decision-making (Phillips et al., 2002; Bennett, 2016). Bennett (2016) argue that perceptions can be more loosely defined than the other concepts mentioned above and define them as a way of observation, understanding, interpretation, and evaluation. Based on this definition, we analyze the perceptions of farmers and citizens regarding ecosystem services supplied by grasslands. To relate to the relationships that individuals have with grasslands, we assess the perceptions of ecosystem services stakeholder-specific, namely the importance that farmers place on ecosystem services when managing their grasslands, but also the suitability of grasslands to provide ecosystem services, as perceived by citizens.

Besides the academic relevance of investigating socio-cultural perceptions of grassland ecosystem services, there is also a growing need to understand sources of potential societal conflicts resulting from different perceptions of ecosystem services. Conflicts between stakeholders can arise when different needs and priorities assigned to ecosystem services prevail (Zoderer et al., 2019b). On the one hand, this is based on the strong social demand for ecosystem services provided by agricultural landscapes in addition to marketed agricultural products. On the other hand, agricultural productivity is important for many farmers (Howley and Dillon, 2012; Howley et al., 2014). These two views can lead to potential conflicts between farmers' agrarian values and specific rules and institutional structures of agro-environmental programs (Chapman, 2019). According to Chapman (2019), however, there are clear potentials for aligning such programs with the needs of different societal actors, including the agricultural sector.

To understand possible conflicts between different actors regarding the supply of ecosystem services, socio-cultural valuation is particularly suitable to capture how the importance of certain ecosystem services differs between stakeholders (e.g., Hummel et al., 2017). While initially understudied (Martín-López et al., 2012), socio-cultural valuation of ecosystem services has received growing attention in recent years (Gomez-Baggethun and Martin-Lopez, 2015; Walz et al., 2016).

As ecosystem services are reflective of the importance that ecosystems provide to humans, management considerations and policies must reflect the perceptions of both the beneficiaries and the small societal sub-groups that directly manage the land. However, in a recent review on socio-cultural valuation of ecosystem services, Walz et al. (2019) found that only 5 out of 48 considered studies involved the combination of active stakeholders (e.g., farmers) and the public outside the agricultural sector. In the context of (Alpine) grasslands, Pachoud et al. (2020), for example, recently studied differences in tourists' and local stakeholders' perceptions of ecosystem services provided by Alpine pastures. Zoderer et al. (2019b) found in a study on spatial (mis)matches that stakeholders differ in their demands for ecosystem service bundles in Alpine landscapes. To further improve the understanding of differences in the perceptions between farmers and citizens regarding a wide range of ecosystem services, we aim to identify 'matches' and 'mismatches' in a novel context. In this study, we examine matches and mismatches between stakeholders' perceived suitability of grasslands to supply specific ecosystem services (citizens) and the respective importance that farmers assign to these ecosystem services in their management decisions. For example, if citizens perceive grasslands as highly suitable to provide specific ecosystem services, but farmers do not place importance on such ecosystem services in their management, there might be trade-offs in the actual supply of the services. Simons and Weisser (2017) highlight that the management goals of farmers need to be clearly defined since both biodiversity and its associated ecosystem services can be increased simultaneously with agricultural production. However, there are trade-offs between agricultural production, ecosystem services, and biodiversity that hamper their equal maximization (Simons and Weisser, 2017; Kaim et al., 2020). Ecosystem services trade-offs based on 24 case studies studied by Turkelboom et al. (2018) revealed that influential users (e.g., land users) take most of the decisions regarding ecosystem services trade-offs, but most of the impact is felt by non-influential stakeholders. (e.g., citizens). Thus, knowledge of matches and mismatches between management considerations and societal perceived suitability can be a key asset for prioritizing management practices that would result in land uses supporting both the sustainable production of agricultural commodities and the supply of ecosystem services required by society. Furthermore, the identification of matches and mismatches rather than just differences in the attitudes towards ecosystem services provides a different way of understanding potential societal conflicts. Our assessment of farmers' perceived importance in management considerations is based on the Theory of Planned Behavior stating that actual management decisions that are contributing to the supply of ecosystem services are influenced by more factors than just attitudes themselves, namely subjective norms and behavioral controls (Ajzen, 1991).

Besides the investigation of matches and mismatches between farmers and citizens, there is a need to consider the heterogeneity of perceptions of ecosystem services within stakeholder groups (Tauro et al., 2018). By investigating the differences in perceptions of ecosystem services within clusters of farmers and citizens and the influence of further socio-economic variables, this research contributes to the consideration of stakeholder heterogeneity in ecosystem services research, a prerequisite to designing more legitimate policies.

The goal of this study is to improve the understanding of the perceptions that farmers and citizens place on the ecosystem services provided by grasslands in pre-Alpine and Alpine environments. We specifically aim to (1) identify matches and mismatches between farmers' considerations towards grassland ecosystem services in their management decisions and citizens' perceptions of grasslands to provide these; (2) explore heterogeneity within both stakeholder groups by identifying clusters based on environmental attitude and farm characteristics; (3) investigate whether the resulted clusters of stakeholders place different perceptions on grassland ecosystem services; (4) and analyze further variables that influence the perceived suitability of citizens and perceived importance in management considerations by farmers. The results of our study are intended to raise awareness of the peoples' views and could serve as foundations for priority setting and better instrumental design of agro-environmental policies.

2. Methods

2.1. Study site and characteristics

Our study area is located in Southern Bavaria (Germany) and comprises parts of the Wetterstein mountains, Bavarian Ammergau Alps, and Alpine foothills. The topography of the study area is very diverse, ranging from a hilly pre-Alpine environment (average of 881 m.a.s.l.) to Germany's highest peak, "Zugspitze," with an altitude of 2,969 m.a.s.l (NASA, 2009). Differences in topography are reflected in the management of agricultural land that is dominated by grassland and shows a gradient of management intensity from north to south. The northern part has a grassland share of close to 50% and is intensively managed (up to seven cutting events per year and consisting of only a few grassland species with high fodder value). In contrast to this, the agricultural land of the southern part has a grassland share of 99%, characterized by low management intensities (LfStat, 2017) (Fig. 1). Grasslands in the southern area include traditional humpback meadows (*Buckelwiesen*) and Alpine pastures. In addition to agricultural land

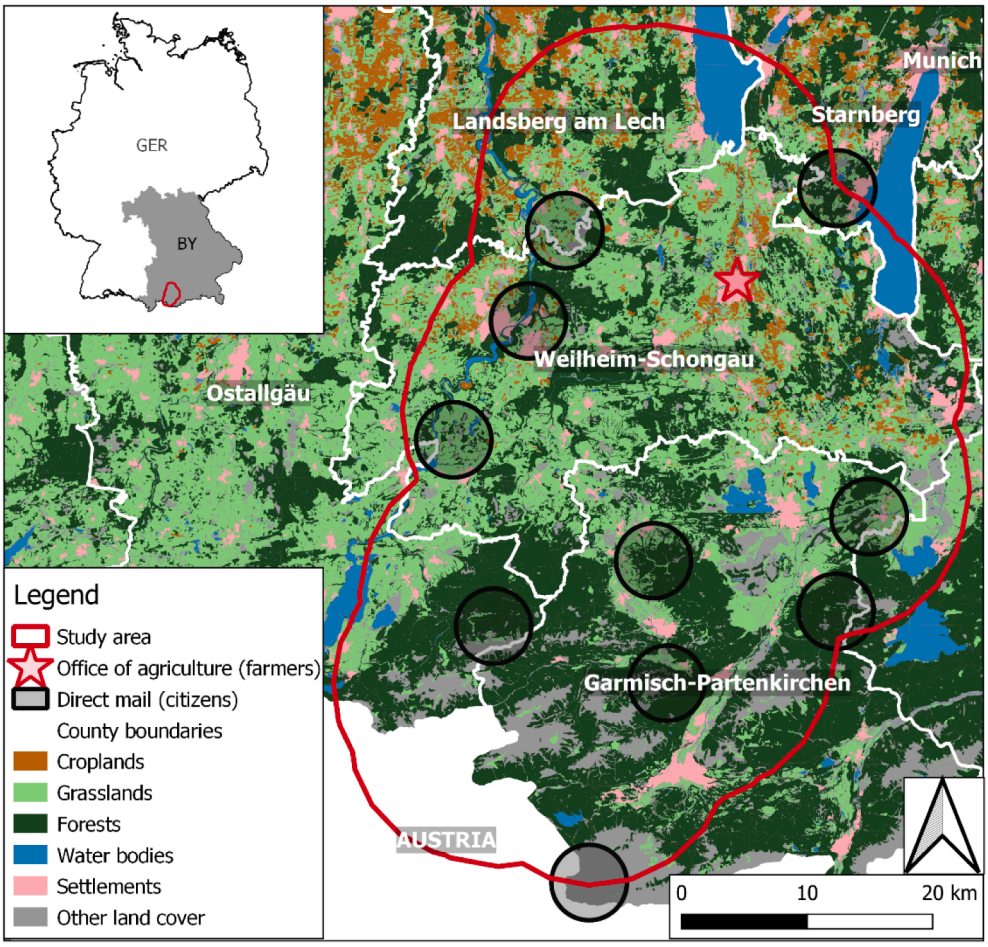

Fig. 1. Location of the study area (red boundary). Surveys with farmers were conducted at the Office of Food, Agriculture, and Forestry Weilheim (red star); surveys with citizens via direct mail to households (black circles).

(36%), the study area consists of forest patches (41.4%), lakes (4.6%), human settlements (4.5%), and other land covers (14%), including mountainous rock and peat environments (LDBV, 2016; Fig. 1).

Different driving forces are underpinning farmers' decisions to change the management of their land. In the mountainous area of the study area, many small-scale farmers have been taken over by larger agricultural farms or have expanded their business towards touristic use. This development has led to the loss of traditional agricultural land use practices, such as the usage of Alpine pastures. At the same time, the management of grasslands in the valleys has been intensified (Ammergauer Alpen GmbH, 2017).

Besides agriculture, which takes a very high economic, ecological, and social importance in the study area, economic activities in the northern part are highly connected to the proximity of Munich while the south is rather dependent on tourism (Ammergauer Alpen GmbH, 2017; AELF Weilheim, 2020).

2.2. Data collection

In 2018, we conducted 609 surveys with farmers (N = 358) and citizens (N = 251) within the study area (Fig. 1). We selected farmers and citizens because they are important beneficiaries of the ecosystem services provided by grasslands in the study area. In addition, farmers are also the most relevant land managers of grasslands. Before conducting the survey, the questionnaires were pre-tested. We pre-tested the questionnaire designed for farmers at the Office of Food, Agriculture, and Forestry in Weilheim by conducting 189 questionnaires. We pre-tested the questionnaire targeting citizens in the pedestrian zone of Garmisch-Partenkirchen by conducting 188 questionnaires.

We adapted the sampling strategy to both stakeholders. Farmers coming from the counties of Garmisch-Partenkirchen, Weilheim-Schongau, and Starnberg received the questionnaire during an application phase for subsidies (February and May 2018) at the Office of Food, Agriculture, and Forestry in Weilheim (see red star in Fig. 1). While they were waiting for an appointment, we provided tablets with an online version of the questionnaire. In the case of citizens, we invited respondents to take part in this research by conducting an online survey at home. In total, 19,777 invitations to conduct the survey were sent via direct mail by the German Federal Post Office to every household located in a 3 km radius of 10 randomly selected points (see black circles in Fig. 1; Table A2). In total, there are approximately 240.000 people living in the study area. All surveys were conducted anonymously and analyzed separately from any personal data.

In both cases, the sample size represents the respective population in the study area at the 95% level, with a sampling error <9%. Regarding farmers, the sampled population corresponded well with the agricultural census data with regards to the distribution of farms in the county and whether farmers work full- or part-time; however, the sampled population over-represented organic farmers (Table 1). In addition, farm sizes of respondents ranged between 10 and 50 hectares, which corresponded with the average of reported farm sizes by the agricultural census: an average of 18 ha in the southern area of the study area and an average of 35 hectares in the northern area (LfStat, 2017). There were 56 farmers who indicated they had heard of the concept of ecosystem services before, while 96 responded that they had never heard about the term prior to taking this survey.

Table 1
Overview of the characteristics of the sampled population of farmers relative to the statistics provided by the census data (LfStat, 2017).

	Distribution of the farms	Sampled population (%)	Census data (%)
County	Weilheim-Schongau (incl. Starnberg)	79.4	67.9
	Garmisch-Partenkirchen	20.6	32.1
Farming as	Full-time job	55.5	42.6
	Part-time job	44.5	57.4
Management	Conventional	64.6	88.5
	Organic	35.4	11.5

Concerning citizens, the sampled population represented the population in terms of age since the average age of respondents was 47 years old, while the census of the Bavarian population shows an average of 45 years old. However, the sample was biased towards those with higher education since 61% of the respondents hold a higher education qualification, while only 29% of the Bavarian population have reached this education level (LfStat, 2020a, 2020b). There were 32 citizens who indicated they had heard about the ecosystem services concept before, while 114 responded said they had never heard about the concept prior to taking the survey.

We designed questionnaires to cover information on the following main themes (Table 2): respondents' knowledge on the ecosystem services approach and the perceptions of the ecosystem services provided by grasslands in the study area. Here we explicitly phrased the questions based on Likert scales differently for farmers and citizens. Citizens were asked about the perceived suitability of grasslands to provide specific ecosystem services and farmers about the importance of considering respective ecosystem services in their management decisions. A mismatch means that citizens perceive grasslands to be suitable for the provisioning of specific ecosystem services, but farmers would not find it important to consider them in their management (or the other way around). Thus, farmers responded to questions in the survey regarding the importance of a range of ecosystem services in their management considerations while citizens, who are not involved in the active day-to-day management of the land, were merely asked about the perceived suitability of grasslands to provide ecosystem services. To keep the questionnaire concise and answerable, we asked the farmers about their intended management considerations only and did not ask them a directly comparable question concerning their perceived suitability towards the supply of ecosystem services by grasslands.

Table 2
Overview of the analyzed parts of the questionnaire, the population targeted in each question section, and examples of questions. For a more detailed version of the questionnaire, see Appendix B.

Question Sections	Population targeted	Examples of questions
Respondents' knowledge of the ecosystem services approach	Farmers and citizens	"Have you heard of ecosystem services before?"
Perception of the ecosystem services provided by grasslands	Farmers Citizens	"Please rate on a scale from (−2 – +2), how important are the following services to you when managing your permanent grassland? Please rate on a scale from (−2 – +2), how suitable do you think permanent grassland (meadows and pastures) is (in the respective study area) for the supply of the following services?
Respondents' relationship with nature and environmental attitude	Citizens	"Are you taking part in activities related to nature?"
Farm data	Farmers	"How large is the size of your farm (in ha)?"
Socio-economic data	Farmers and citizens	"What is your highest school degree? Please choose."

In addition, the survey targeting citizens included questions about respondents' environmental attitudes (i.e., connection with nature, activities respondents do in nature, and their consumption priorities). The questionnaire targeting farmers included questions about the farm characteristics, such as the location of their fields, size of their farm, or whether the management was organic or conventional. Both groups were asked about socio-economic characteristics (e.g., age, education level; see Table A1). To investigate the socio-cultural perceptions of ecosystem services provided by grasslands, we asked respondents to rate 11 ecosystem services displayed in random order on a 5-point Likert-scale: Fodder production, animal production, energy plant production, soil fertility, groundwater quality, climate regulation, soil erosion reduction, flood risk reduction, pollination, biological pest control, and recreation (Appendix B.). The ecosystem services addressed are based on the national German framework elaborated under Action 5 of the EU Biodiversity Strategy to 2020 (Mapping Ecosystem Services) and were published in Rabe et al. (2016). We have chosen the selected ecosystem services due to their relevance in the agricultural grassland system. In the question phrasing, we specifically did not mention "ecosystem services" to make the question answerable to all. Hence, no prior knowledge of the ecosystem services concept was necessary.

2.3. Data analysis

First, we conducted a descriptive statistical analysis to understand how farmers and citizens perceived ecosystem services provided by grasslands. Then to analyze whether there were statistically significant differences in the rating of specific ecosystem services, indicating a mismatch between perceived suitability of grasslands to provide specific ecosystem services by citizens and importance of these in management considerations by farmers, we conducted the Mann-Whitney-U-Test. We thereby assume that a mismatch exists if the importance farmers assign to ecosystem services is statistically significantly different to the citizens' perceived suitability of grasslands to provide such. For the statistical analysis, we used R Studio Version 1.2 (R Studio Team, 2015).

Second, to understand the existing heterogeneity within these two stakeholder groups, we ran a model of clustering and dimension reduction (CDR) consisting of a Principal Component Analysis (PCA) followed by k-Means clustering (Vichi et al., 2018; Markos et al., 2019). We selected these statistical methods due to the presence of both categorical and numerical variables in the data (Hwang et al., 2010; Vichi et al., 2018). For this analysis, we used variables relating to environmental attitude for citizens and farm data for farmers. We used the R package *clustrd* to conduct the analysis (Markos et al., 2019) and the R package *NbClust* to determine the most likely amount of clusters present (Charrad et al., 2014). Then, to explore differences in the perception of ecosystem services between the resulted clusters of farmers and citizens, we conducted the Mann-Whitney-U-Test and the Kruskall-Wallis-Test, respectively. We conducted this analysis separately for farmers and citizens.

Third, to determine which respondents' characteristics influence the perception of ecosystem services, we conducted Redundancy Analysis (RDA), which relates dependent variables with their potential predictors (Legendre et al., 2011). We conducted two separate RDAs, one for farmers' management importance and one for citizens' perceived suitability. Since previous research has found that socio-economic variables (e.g., gender, education level, age) and previous knowledge on ecosystem services affect the perception of ecosystem services (Martín-López et al., 2012; Oteros-Rozas et al., 2013), we selected these variables as independent for both stakeholders. In addition, we included the clusters resulting from the corresponding analysis. As dependent variables, we selected the Likert-based ratings of the importance of the ecosystem services provided by grasslands. To identify the significance of the influence of the independent variables, we conducted a Monte Carlo Permutation test (999 permutations). We used the R-package

vegan v. 2.4 for this analysis (Oksanen et al., 2019).

3. Results

3.1. Perception of grassland ecosystem services by farmers and citizens

We found that farmers considered all ecosystem services provided by grasslands to be important in their management decisions and that citizens perceive this ecosystem type as suitable to deliver them (Fig. 2). An exception is the production of energy by plants, which is very unimportant for farmers. At the same time, citizens think that grassland is very unsuitable to deliver this service. We found a mismatch between the importance in management decisions by farmers and the perceived suitability to deliver the service by citizens for fodder production, energy plant production, soil fertility, flood risk reduction, and recreation.

3.2. Ecosystem service perceptions expressed by different farmer types

The PCA and k-means revealed two clusters of farmers (Fig. 3): *Farmers "Subalp"* and *Farmers "Alp."* *Farmers "Subalp"* were characterized by cultivating large intensively managed farms, who work full-time as farmers. Respondents belonging to this cluster were predominantly

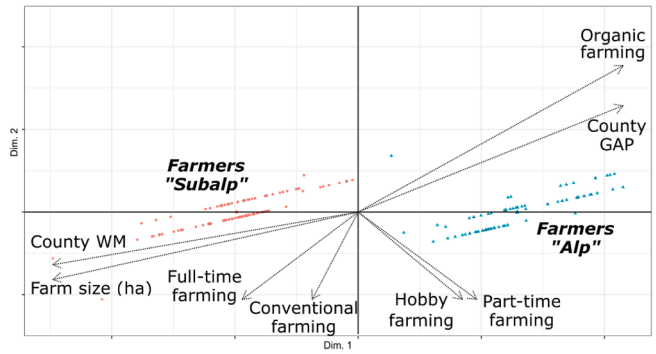

Fig. 3. Two clusters of farmers were revealed by the Principal Component Analysis followed by k-means clustering. (1) Farmers "Subalp" (red dots) represents farmers owning larger and more intensively managed farms who also work full-time as farmers. (2) Farmers "Alp" (blue dots) represents farmers owning smaller farms that are managed organically and who work part-time as farmers or have farming as a hobby. WM = Weilheim-Schongau (including Starnberg); GAP = Garmisch-Partenkirchen.

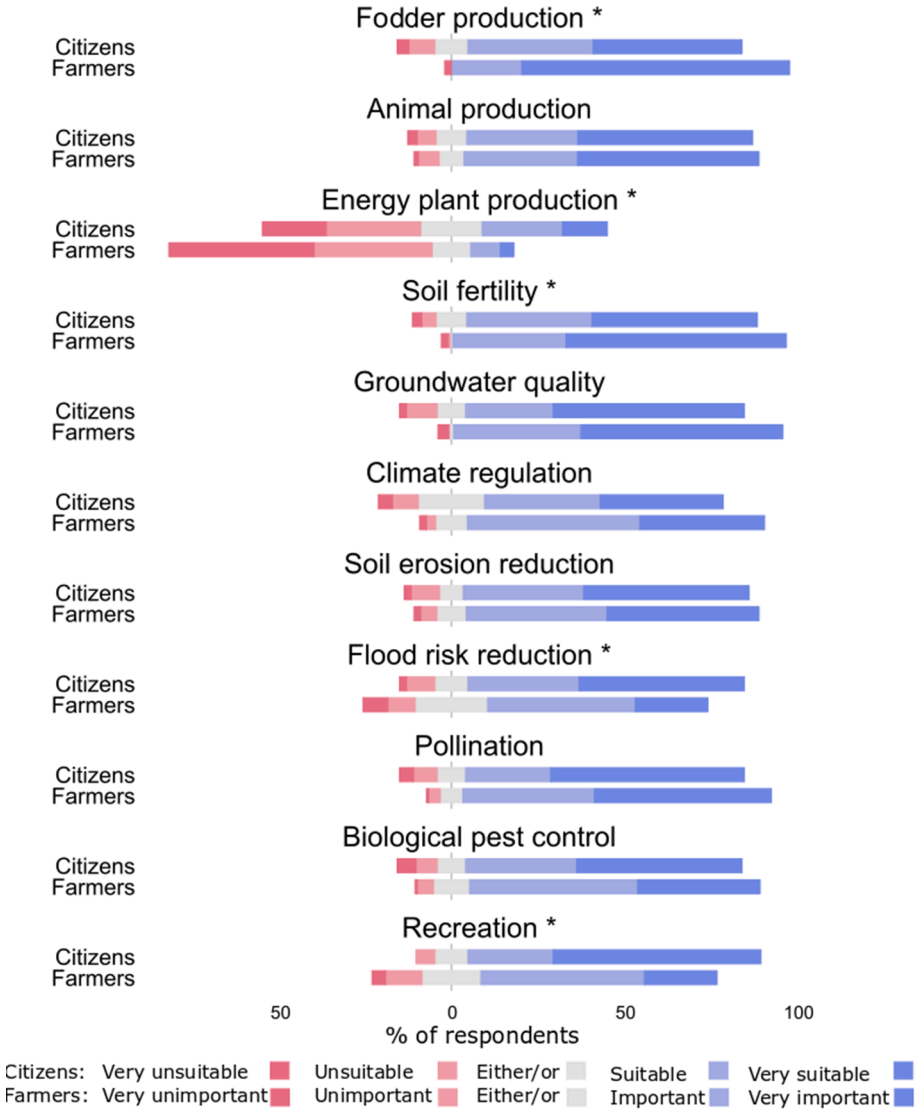

Fig. 2. Perception of grassland's ecosystem services expressed by farmers and citizens. Significant statistical differences ($p < 0.05$) are marked with *.

working in the pre-Alpine zones of the northern part of the study area (i.e., counties Weilheim-Schongau and Starnberg). *Farmers "Alp"* were characterized by working on rather small, organically managed enterprises who farm either part-time or consider themselves as hobby farmers. Farms belonging to this cluster were predominantly located in the southern, Alpine county of Garmisch-Partenkirchen.

We found significant differences between the two clusters of farmers regarding the perceived importance of three regulating services (soil erosion reduction, pollination, biological pest control) and recreation. These ecosystem services were seen as more important in their management by *Farmers "Alp"* than by *Farmers "Subalp"* (Fig. 5a).

3.3. Ecosystem service perception expressed by different citizen types

The PCA and k-means revealed three clusters of citizens (Fig. 4): *Citizens "Environ," Citizens "Employ,"* and *Citizens "Other." Citizens "Environ"* were characterized by conducting activities in nature in their free time, such as birdwatching or collecting non timber forest products (NTFPs). Respondents belonging to this cluster take biodiversity or ecosystem services into consideration when buying groceries. *Citizens "Employ"* were characterized by being employed in a job related to nature or being involved in hunting, either as a hobby or as an occupation. *Citizens "Other"* were characterized by respondents not interested in any of the activities related to nature.

We found significant differences between the three clusters of citizens regarding the perceptions of six regulating services (groundwater quality, climate regulation, soil erosion regulation, flood risk reduction, pollination, and biological pest control) that were perceived as more suitable to be delivered by grasslands by *Citizens "Environ"* than the other clusters of citizens. By contrast, *Citizens "Employ"* perceived recreation as more suitable than the other two clusters of citizens (Fig. 5b).

3.4. Factors influencing perceptions of ecosystem services

Redundancy analyses (RDAs) for both farmers and citizens indicated a statistically significant association between the respondents' socio-economic characteristics, clusters, and perception of grassland ecosystem services (farmers: $p = 0.016$ with 999 permutations; citizens $p < 0.01$ with 999 permutations) (Table 3).

In Fig. 6a, Axis 1 (62.3%) of the RDA for farmers shows in the positive scores an association between those farmers that manage grasslands less intensively in the Alps (*Farmers "Alp"*) and higher importance in their management for all ecosystem services, except for fodder production. In addition, the negative scores of this axis showed that those male farmers with a higher level of education who belong to *Farmers "Subalp"* expressed less importance for ecosystem services. Axis 2 (19.3%) showed a gradient between those farmers who never heard about the concept of ecosystem services (positive scores) and elderly farmers (negative scores). While those farmers who had never heard about ecosystem services expressed high importance to provisioning services, such as animal and fodder production, elderly farmers expressed higher importance to regulating services, such as groundwater quality and biological pest control (Fig. 6a).

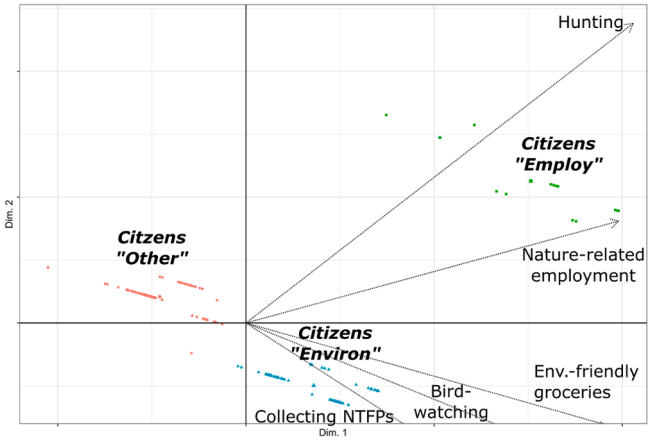

Fig. 4. Three clusters of citizens: (1) Citizens "Environ" (blue dots) represent environmentally interested respondents, (2) Citizens "Employ" (green dots) include people employed in a job related to nature or going hunting, and (3) Citizens "Other"(red dots) who do not align to any of these environmentally-related variables. NTFPs = Non timber forest products.

The positive scores of Axis 1 (82.1%) of the RDA for citizens revealed an association between *Citizens "Environ"* and higher suitability to be delivered by grasslands for all ecosystem services, except for fodder production. The negative scores of this axis showed that male citizens expressed lower values for all ecosystem services besides Fodder production. Axis 2 (7.9%) showed in the positive scores that those elderly citizens who had never heard about the concept of ecosystem systems expressed higher suitability of grasslands to supply some provisioning and regulating services such as animal production, soil erosion reduction, biological pest control, and energy plant production and lower suitability for climate regulation, recreation, and groundwater quality (Fig. 6b).

4. Discussion

The goal of this study was to gain further insight into the perceptions that citizens assign to grassland ecosystem services and the respective management importance that are assigned by farmers. We further aimed to identify the variables driving the perceived suitability and management considerations in a pre-Alpine and Alpine environment. Firstly, we discuss the matches and mismatches of ecosystem services regarding farmers' importance in their management and citizens' perceptions on the suitability of grasslands to provide such. Secondly, we take up the clusters of farmers and citizens and their different perceptions of ecosystem services. Thirdly, we discuss the variables influencing these differences. Finally, we address some general limitations of our methodology.

4.1. Matches and mismatches between citizens' perceived suitability and farmers' management consideration

The results reveal an overall high number of matches between farmers' indicated importance of ecosystem services in their management and citizens' perceived suitability of grasslands to provide ecosystem services. Overall, this is in line with other studies examining perceptions of both farmers and non-farmers on ecosystem services in agricultural environments (e.g., Bernués et al., 2013; Howley et al., 2014; Pachoud et al., 2020). According to our results, farmers perceived one of the major provisioning services of grasslands, fodder production, at a higher level than citizens did. This result supports other studies' findings that people who receive economic benefits from an ecosystem service also place a higher perception level on it (e.g., Howley et al., 2014; Bidegain et al., 2019; Zoderer et al., 2019b).

Similarly, a mismatch was found for the ecosystem service soil fertility, which was rated higher by farmers for their management than by citizens in terms of their perceived suitability. An earlier study on grassland ecosystem services by Lamarque et al. (2011) also found that soil fertility was positively associated with marketed services such as forage yield and quantity by farmers. This is in line with other studies comparing farmers and citizens. For example, Bernués et al. (2013) found higher importance attributed to regulating services that relate to the farming activity such as soil fertility by farmers than by citizens in a study on mountain farming in north-eastern Spain.

Contrary to soil fertility, citizens rated flood risk reduction as more suitable to be delivered by grasslands than farmers did concerning their importance in management considerations. This could be caused by a

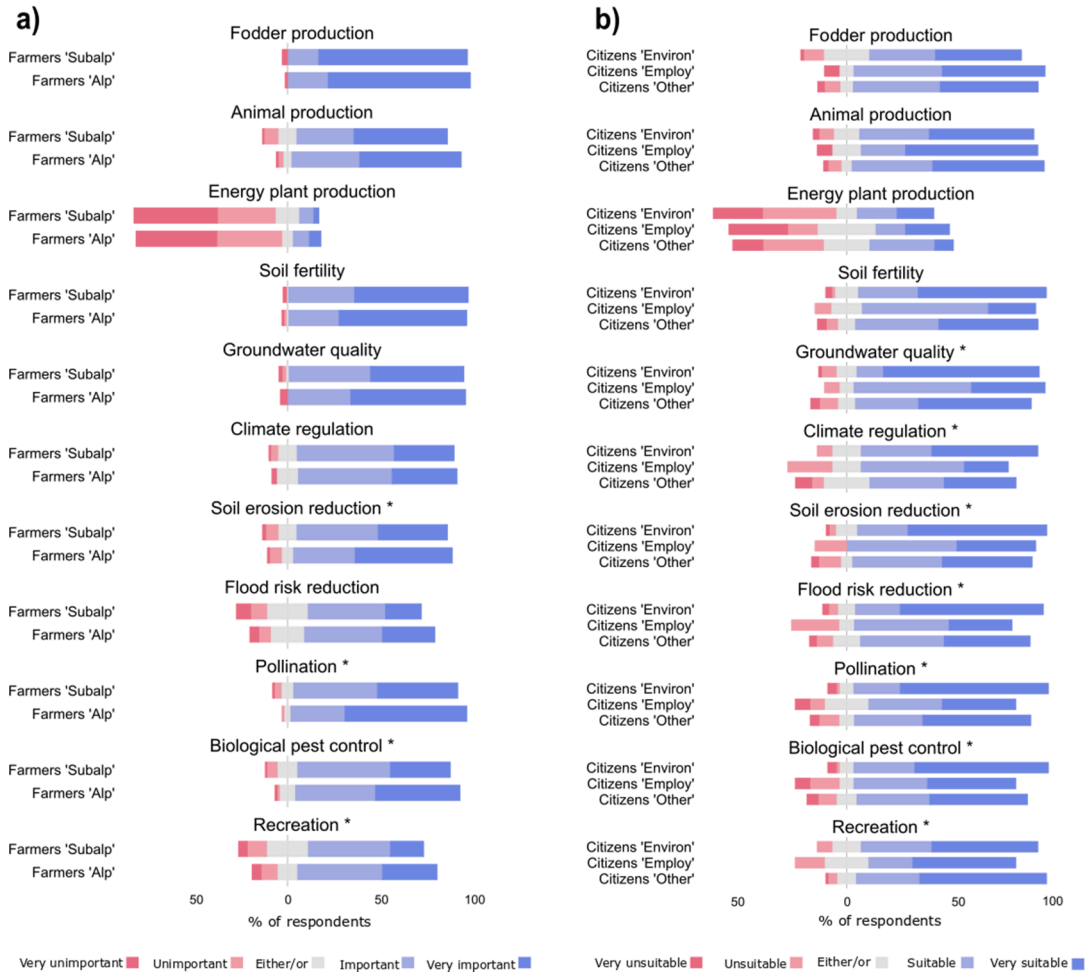

Fig. 5. Perception of ecosystem services provided by grasslands split by two clusters of farmers (a): Farmers "Subalp" and Farmers "Alp" and three clusters of citizens (b): Citizens "Environ," Citizens "Employ," and Citizens "Other". Significant statistical differences ($p < 0.05$) are marked with * (based on Mann-Whitney-U-Test and Kruskal-Wallis-Test).

Table 3
Results of the redundancy analyses (RDAs) for farmers and citizens.

	RDA Farmers		RDA Citizens	
	Axis 1	Axis 2	Axis 1	Axis 2
Eigenvalue	0.311	0.096	0.598	0.057
Proportion explained (%)	62.23	19.27	82.13	7.88
Cumulative proportion explained (%)	62.23	81.59	82.13	90.01

strong awareness of citizens' need for flood protection (Ryffel et al., 2014). Furthermore, the strong current discussion about increased measures of flood protection and biodiversity preservation along floodplains, which farmers must comply with, might have influenced the perceived importance of the flood risk reduction service by farmers (Pers. Comm., 2019).

We did not find a mismatch for the ecosystem services water quality and climate regulation, which are regulating ecosystem services that are also often described in a public good context. In fact, Faccioni et al. (2019) found that non-farmers were more critical of greenhouse gas emissions and water quality than farmers in Alpine agroecosystems. However, former research aligns with our findings. For example, Iniesta-Arandia et al. (2014) found, in the Sierra Nevada Mountain (Spain), that there were no differences in the social perceptions of both services between farmers and non-farmers. Howley et al. (2014) found in a study in Ireland that ensuring high water quality was the second most important environmental issue for both farmers and the general public. These results again strengthen the need for place-based and context-specific research on socio-cultural valuation of ecosystem services (Lamarque et al., 2011; Martín-López et al., 2012; Faccioni et al., 2019).

Interestingly, we did not find a mismatch between farmers and citizens regarding animal production on open grassland. A plausible explanation of this result is that respondents identify agricultural food production not only as a provisioning service but also as a cultural ecosystem service creating landscape aesthetics or social identity (Pereira et al., 2005). Animal production on grasslands based on outdoor grazing is an important aspect of the cultural identity of the people living in the area (UNESCO, 2015). Furthermore, Bidegain et al. (2019) found in a biosphere reserve in Chile that a decrease in small-scale agriculture can challenge the local culture and way of life, a trend that is also clearly observable in the study area (Ammergauer Alpen GmbH, 2017). Le Clec'h et al. (2019) in general found higher provisioning of ecosystem services on pastures than on meadows in a case study in Switzerland. Hence, a potential association of other ecosystem services related to pastures could have led to the overall high importance of "animal production on open grasslands." In general, pastures of low management intensity favor multiple ecosystem services, such as climate regulation, recreation, and biodiversity conservation, except for forage provisioning (Le Clec'h et al., 2019).

Grasslands are important providers of additional cultural ecosystem services, such as recreation (Bengtsson et al., 2019). Contrasting to the

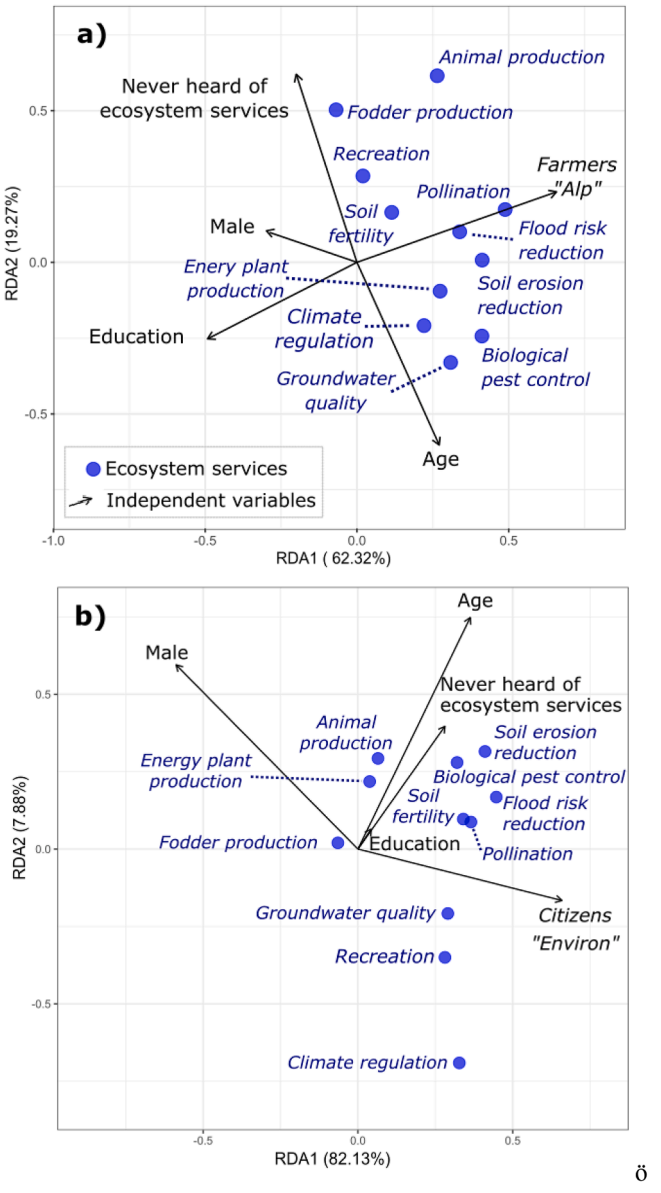

Fig. 6. Redundancy analysis results for (a) farmers and (b) citizens. All independent variables are statistically significant with $p < 0.001$.

Swiss lowlands, where grassland dominated landscapes compared to cropland or mixed landscapes received the least aesthetic appreciation in a study by Junge et al. (2011), in mountain areas, highly valued landscape aesthetics are heavily dominated by grassland systems (Zoderer et al., 2019a; Schirpke et al., 2016; Pachoud et al., 2020). In our study area, characterized by both Alpine mountains and pre-Alpine hills, a high perception level for recreation provided by grasslands can be observed. Though, we found a mismatch with a significantly higher perceived suitability of grasslands to deliver recreation by citizens than the management importance assigned by farmers. This mismatch aligns with other studies' findings (e.g., Bernués et al., 2013; Howley et al., 2014; Bidegain et al., 2019). Nevertheless, this result might have been influenced by the way the question was asked: "recreation in the open landscape on grasslands." Farmers mentioned that they sometimes have issues with tourists disrespectfully trespassing on their grasslands or conflicts between cows and dogs indicating combating interests (Pers. Comm., 2019).

The only grassland ecosystem service that is rated as (very) unimportant by both groups is energy plant production, with a mismatch between farmers and citizens. This seems surprising at first glance as energy plant production also provides income for farmers. Hence, farmers interested in economic or personal returns would be expected to place similarly high importance in their management on energy plant as on fodder production (Bidegain et al., 2019). Our results indicate that farmers put more importance on producing food rather than energy on their grasslands. This corresponds to other studies' findings that farmers favor food production on their land rather than biomass production of energy plants (Dietze et al., 2019).

4.2. Clusters within the stakeholder groups

The cluster characteristics indicate that *Farmers "Alp"* consists of more farmers that practice less intensive grassland management than *Farmers "Subalp."* This is a fairly reasonable result as the farmers in the cluster *Farmers "Alp"* are frequently located in the Alpine county of Garmisch-Partenkirchen, dominated by an agriculturally disadvantaged setting due to its topography and climatic variability. The respective farmers also participated in more agro-environmental payment schemes, such as the Bavarian cultural landscape program "KULAP" (LfStat, 2017). These agro-environmental schemes support farmers in maintaining cultural landscapes in a sustainable way (StMELF, 2020). Plieninger and Bieling (2013) strengthen the point that subsidies like these are essential components in maintaining the sustainable supply of ecosystem services in cultural landscapes. As unique cultural landscapes, the studied grasslands in the Alpine county of Garmisch-Partenkirchen are currently on the tentative list of attaining UNESCO World Cultural Heritage status (UNESCO, 2015). Furthermore, *Farmers "Alp,"* characterized by part-time farming and less intensive farming practices, perceived regulating services such as pollination and biological pest control as more important than *Farmers "Subalp."* Lamarque et al. (2011) also found that part-time farmers value cultural ecosystem services such as recreation higher as these farmers are involved in tourism, which is also the case for our Alpine case study area around Garmisch-Partenkirchen (Ammergauer Alpen GmbH, 2017). Junge et al. (2011) identified that organic farmers had a higher appreciation for landscapes with ecological compensation areas. These results indicate the favoring of public goods provided by the landscapes in management considerations of *Farmers "Alp."*

The clusters of citizens that we determined (*Citizens "Environ," Citizens "Employ,"* and *Citizens "Other"*) differed strongly in their environmental awareness and dependence on nature for personal income. Besides recreation, all other significantly different ecosystem services were rated higher by Citizens "*Environ*" as this cluster is more environmentally aware. Only recreation was perceived at a higher level by Citizens *"Employ"* than by Citizens *"Environ."* This could potentially be explained by hunters who belong to *Citizens "Employ"* who see their activity as a recreational sport (García-Nieto et al., 2014) and appreciate grasslands' open spaces.

4.3. Variables influencing perceptions of ecosystem services

Investigating the heterogeneity of farmers and citizens into clusters was highly valuable for better understanding the variables driving the perceptions of ecosystem services. Specifically, regulating services (such as pollination, reduction of soil erosion and flood risk, and biological pest control) were correlated with more environmentally aware citizens or farmers that practice less intensive grassland management. This also relates to the actual supply of ecosystem services as grasslands with low management intensity provide more ecosystem services than grasslands with high management intensity, except for forage provisioning (Simons and Weisser, 2017; Le Clec'h et al., 2019). Besides this clustering according to environmental attitudes, socio-economic variables such as age and gender also show a statistically significant influence on the perception of ecosystem services.

The age of farmers is positively correlated with perceptions of

regulating services and negatively with perceptions of provisioning services. This is comparable to results by Howley et al. (2014), who found that elderly respondents had a higher appreciation for maintaining traditional farming landscapes. Age by itself is unlikely to explain these differences in the perceptions but is an indicator concerning social, economic, and technological differences between respondents (Tauro et al., 2018). Other literature suggests that elderly farmers value regulating services higher as they appreciate these services for ecosystem functioning, which could be linked to their higher local ecological knowledge (LEK) (Martín-López et al., 2012; Iniesta-Arandia et al., 2015). The loss of LEK of grassland ecosystem services is concerning as it relates to lower levels of social awareness of regulating services. This explanation aligns with findings in other ecosystems throughout eastern, central, and western Europe, where LEK is likewise being lost at alarming rates (Martín-López et al., 2018).

Education level showed very little effect for citizens. A possible explanation for our results is the very high overall educational level of citizens who responded to our survey. Furthermore, Junge et al. (2011) explained a similarly low effect of education for aesthetic appreciation by the findings that landscape characteristics had a more considerable influence on the perception than socio-demographic characteristics. For farmers, education level did show an effect mainly for provisioning services, which means that higher educated farmers have a higher priority for producing ecosystem services with personal benefits.

In both actor groups, women show a closer connection to regulating services than men do. This result corresponds well with other findings in ecosystem services research that link perceived values of ecosystem services with the gender of the respondents. Martín-López et al. (2012) found higher recognition of regulating services by women in protected and non-protected areas in Spain and higher values for provisioning services by men. In a recent review from forest and mangrove ecosystems, Yang et al. (2018) found that women value regulating services such as water quality, erosion control, soil formation, and habitat conservation higher than men do, but men place higher values on provisioning services such as fuel or timber. More research is needed to generalize these results, as gender roles by themselves are diverse, and they often interplay with other variables such as wealth, education, traditions, and age (Fortnam et al., 2019).

4.4. Methodological limitations of the study

While surveys are a reliable way to capture information about individual perceptions and collective preferences, the results need to be carefully interpreted concerning generalization (Andert et al., 2019). Our citizen surveys advertising questionnaires on "agriculture, climate change, and nature conservation" could have predominantly motivated people with a rather environmentally-friendly attitude and higher education level to participate. The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and the Federal Agency for Nature Conservation (BfN) (2017) clustered citizens of Germany into different socio-cultural milieus. The respondents of our study belong mostly to one of the higher social status milieus who have been associated with a strong reliance upon nature. These implications in the citizens survey partially also hold true for the farmers' survey that, as indicated in Table 1, attracted more organic farmers than there are proportionally present in the study area. As we identified an impact of organic farming on the importance assigned to grassland ecosystem services, the generalization of the results to the entire population of farmers in the study area needs to be done with caution.

We further acknowledge some uncertainty in the results that arise when comparing results obtained from two different questions: farmers' management considerations and citizens' perceived suitability towards ecosystem services delivered by grasslands. Yet, the use of these two questions was necessary to adapt the survey to the reality of both stakeholders and to analyze mismatches and matches between them. Another point of discussion are the different situations when the surveys were conducted, which might have influenced the results. While farmers filled out the questionnaire on a tablet during their waiting time at the local Office of Food, Agriculture, and Forestry, citizens received a postcard by direct mail with the invitation to take part in an online survey on their own device at the time of day they wanted to. Also, surveys targeting farmers were conducted in spring 2018 (January to May), while citizens were asked to take part in the study in October 2018.

5. Conclusion

This study was conducted to unravel matches and mismatches between the importance that farmers assign to grassland ecosystem services in their management considerations and the corresponding perceived suitability of grasslands to supply ecosystem services in a pre-Alpine and Alpine environment. As recent studies suggested to investigate the heterogeneity among stakeholders regarding socio-cultural valuation, our focus was to integrate a cluster analysis with the assessment of stakeholders' perceptions followed by further statistical analyses. The results of our study brought several conclusions: although most ecosystem services assessed were highly perceived by all stakeholders, statistically significant (i) mismatches were found between farmers and citizens, (ii) differences existed between the clusters of *Farmers "Alp"* and *Farmers "Subalp,"* (iii) and between the clusters of environmentally interested, less environmentally interested, and environmentally employed citizens. In addition, we found that gender, age, and education influenced ecosystem service perceptions of both stakeholder groups. These results highlight the need to extend research on the perceptions of grassland ecosystem services as these depend on case-specific variables. The matches and mismatches may also serve as a basis for further policy-related research and spatial planning. Specifically, the importance citizens assigned to ecosystem services may justify that agro-environmental payments are taking ecosystem services in agricultural landscapes more directly into account. This would allow to address income loss in agriculture because of management towards such ecosystem services farmers are not primarily interested in.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.

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Appendix A.

Table A1. Socio-economic characteristics of the respondents for the statistical analysis

Characteristics	Farmers	Citizens
Gender		
Male	76.3%	61.6%
Female	23.7%	38.4%
Age		
18-25	2.6%	6.2%
26-30	6.6%	7.5%
31-35	11.2%	6.8%
36-40	11.2%	11.0%
41-45	12.5%	11.0%
46-50	17.1%	11.6%
51-55	17.8%	17.1%
56-60	8.6%	8.9%
61-65	8.6%	8.2%
66-70	3.9%	6.8%
>70	0.0%	4.8%
Heard of ES		
yes	36.8%	21.9%
no	63.2%	78.1%
Education		
No school diploma	0.0%	0.7%
Lower secondary education	53.3%	7.5%
Middle secondary education	31.6%	24.0%
Higher secondary education	15.1%	67.8%

Table A2. Distribution of households in the 10 randomly selected points.

id	Municipality	Number of households
0	82438 Eschenlohe	409
1	87642 Halblech	1,614
2	86989 Steingaden	894
3	82491 Eibsee	171
4	82442 Wurmansau	1,543
5	86974 Apfeldorf	427
6	82327 Tutzing	3,582
7	86971 Peiting	8,249
8	82488 Ettal	1,838
9	82439 Großüweil	1,050
		19,777

Appendix B. Relevant questions of the questionnaire

For the full version of the questionnaire, please contact the corresponding author.

1. SUSALPS Farmers – 2018 Weilheim

Start of Block: Introduction

Leistungen von Natur und Landschaft in Bayern
Services from Nature and Landscape in Bavaria

Dieser Fragebogen richtet sich an die **Landwirte Bayerns** und ist Teil des Forschungsprojektes SUSALPS der Universität Bayreuth. In SUSALPS geht es um die nachhaltige Nutzung von Natur und Landschaft (speziell Grünland) unter dem Einfluss des Klimawandels.
This survey is intended for farmers in Bavaria and is part of the research project SUSALPS at the University of Bayreuth. SUSALPS is working on the sustainable use of Nature and the Landscape (with a focus on grasslands) under the influence of climate change

Ihre Teilnahme dauert ca. 15 min und ist absolut **freiwillig** sowie **unverbindlich**. Die Fragen sind **anonym** und lassen sich nicht auf Ihre Person zurückführen. Darüber hinaus werden Ihre persönlichen Antworten streng vertraulich behandelt und nicht an Dritte weitergegeben.
Your participation takes app. 15 min and is entirely optional and non-binding. The questions are anonymous and cannot be traced backed to you. We will also treat your personal answers as strictly confidential and they will not be passed on to third parties.

Bitte füllen Sie den Fragebogen vollständig und so genau wie möglich aus. Die Qualität der Forschungsergebnisse hängt davon ab.
Please answer the survey as complete and exactly as possible. The quality of our research results depends on this.

Q3.1 Haben Sie schon mal den Begriff Ökosystemleistungen gehört?
Have you ever heard of ecosystem services before?

○ Ja Yes

○ Nein No

Q3.2 Wenn ja, aus welcher Quelle?
If yes, from what source?

Q3.3 Was stellen Sie sich unter Ökosystemleistungen vor?
What do you imagine Ecosystem Services to be?

_____

Q7.1 Wie wichtig sind Ihnen bei der Bewirtschaftung **Ihres Dauergrünlandes** folgende Leistungen?
How important are the following ecosystem services for you when managing your permanent grasslands?

Sehr unwichtig (- -)	Unwichtig (-)	Weder noch (- / +)	Wichtig (+)	Sehr wichtig (+ +)	Ist mir unbekannt (…)
very unimportant	unimportant	either/or	Important	Very important	Unknown

Produktion von Tierfutter im Dauergrünland (z.B. Grassilage, Heu)
Production of animal fodder (e.g. grass silage, hay)
Tierproduktion im Freiland (z.B. Milchkühe und Ochsenmast auf Weiden)
Animal production on open land (e.g. dairy cows on pastures)
Produktion von Energiepflanzen im Dauergrünland (Grassilage für Biogasananlagen)
Production of energy by plants on permanent grassland (grass silage for biogas plants)
Erhalt der Bodenfruchtbarkeit (durch natürliche Bodenprozesse)
Retention of soil fertility (by natural soil processes)
Schutz der Grundwasserqualität (durch Stickstoffrückhalt in der Vegetation)
Protection of ground water quality (through nitrogen retention in the vegetation)
Regulation des globalen Klimas (durch Aufnahme von Klimagasen wie CO2 und Speicherung in Böden und Vegetation)
Regulation of the global climate (by uptake of climate gasses such as CO2 and storing insoils and vegetation)
Minderung der Wassererosion (durch Vegetationsdecke)
Reduction of water erosion (through vegetation)
Hochwasserschutz (durch Retentionsflächen in Auenbereichen)
Flood risk reduction (by retention in riparian areas)
Bestäubung von Kulturpflanzen (durch wildlebende Insekten)
Pollination of cultural plants (by wild insects)

Biologische Schädlingskontrolle (durch wildlebende Insekten und Vögel)
Biological pest control (by wild insects and birds)
Erholung in der freien Landschaft (durch Naturerleben und Landschaftästhetik)
Recreation in the open land (by experiencing nature and landscape aesthetics)

Q12.1 Welche Form der Landwirtschaft betreiben Sie?
What type of agriculture are you working on ?

- ○ Konventionell Conventional
- ○ Ökologisch Organic

Q12.3 Landwirtschaft ist für Sie:
Agriculture is for you:

- ○ Haupterwerb (arbeite ausschließlich als Landwirt) Full time work
- ○ Nebenerwerb/Zuerwerb Part time work
- ○ Hobby Hobby

Q12.7 Meine landwirtschaftlichen Flächen befinden sich im Landkreis (Mehrfachnennung möglich):
My agricultural land is situated in the following counties (multiple counties possible)

- ○ Landkreis 1 County 1 _____
- ○ Landkreis 2 County 2 _____
- ○ Landkreis 3 County 3 _____
- ○ Landkreis 4 County 4 _____

Q12.8 Wie groß ist die von Ihnen bewirtschaftete Fläche (in Hektar)?
How large is the size of your farm (in ha)?

_____

Q13.1 Welches Geschlecht haben Sie?
What is your gender?

- ○ männlich male
- ○ weiblich female
- ○ keine Angaben no answer

Q13.2 Welcher Alterskategorie gehören Sie an?
What age category do you belong to?

- o Unter 18 below 18
- o 18-25
- o 26-30
- o 31-35
- o 36-40
- o 41-45
- o 46-50
- o 51-55
- o 56-60
- o 61-65
- o 66-79
- o > 70

Q13.3 Welchen höchste allgemeine Schulausbildung haben Sie?
What is your highest level of general education you attended?

- ○ Haupt-(Volks-)schulabschluss Lower secondary education
- ○ Abschluss der polytechnischen Oberschule Middle secondary education
- ○ Realschul- oder gleichwertiger Abschluss Middle secondary education
- ○ Fachhochschul- oder Hochschulreife Higher secondary education / University entrance qualification
- ○ Ohne allgemeinen Schulabschluss No school diploma
- ○ Keine Angabe No answer

2. SUSALPS Citizens – 2018 **Online survey**

Online-Umfrage 2018 "Klimawandel, Landwirtschaft und Naturschutz"
Online Survey 2018 „Climate change, Agriculture and Nature conservation“

Dieser Fragebogen richtet sich an die **Bevölkerung Bayerns*** und ist Teil des Forschungsprojektes SUSALPS der Universität Bayreuth. In SUSALPS geht es um die nachhaltige Nutzung von Natur und Landschaft (speziell Wiesen und Weiden) unter dem Einfluss des Klimawandels.
This survey is intended for **citizens in Bavaria*** and is part of the research project SUSALPS at the University of Bayreuth. SUSALPS is working on the sustainable use of Nature and the Landscape (with a focus on grasslands) under the influence of climate change.

Ihre Teilnahme dauert ca. 12 min und ist absolut **freiwillig**. Die Antworten werden **anonymisiert** und lassen sich nicht auf Ihre Person zurückführen. Ihre persönlichen Angaben werden streng vertraulich behandelt und nicht an Dritte weitergegeben.
Your participation takes app. 15 min and is entirely **optional** and non-binding. The questions are anonymous and cannot be traced backed to you. We will also treat your personal answers strictly confidential and they will not be passed on to third parties.

Bitte füllen Sie den Fragebogen **vollständig und so genau wie möglich** aus. Die Qualität der Forschungsergebnisse hängt davon ab.
Please answer the survey as **complete and exact as possible**. The quality of our research results depends on this.

Es können auch gerne **mehrere Personen in Ihrem Haushalt** einen Fragebogen ausfüllen - einfach eine Umfrage abschliessen und eine neue öffnen. Wichtig ist aber, dass ein Fragebogen jeweils nur durch eine Person bearbeitet wird.
It is possible that **multiple people in your household** fill out this survey – simply close the survey and open a new one. It is important that each survey is only filled out by one single person

Wir freuen uns auf Ihre Meinung!
We are looking forward to hearing your opinion!

*) In den Landkreisen Bayreuth, Kulmbach und Hof sowie den Landkreisen Garmisch-Partenkirchen, Ostallgäu und Weilheim-Schongau wurde Ihr Haushalt zufällig ausgewählt.
*) We randomly selected households in the counties of Bayreuth, Kulmbach and Hof as well as Garmisch-Partenkirchen, Ostallgäu and Weilheim-Schongau to take part in this study.

Q2.1 **Zuerst einige allgemeine Fragen zu Natur und Landschaft**
First, some general questions to nature and landscape

Q2.2 Nutzen Sie privat Natur und Landschaft in Bayern?
Do you privately use nature and the landscape in Bavaria?
Are you taking part in activities related to nature?

- ja yes
- nein no
- weiss nicht don't know

Q2.3 Wenn ja, für welche privaten Aktivitäten nutzen Sie Natur und Landschaft in Bayern? Bitte klicken Sie an.
If yes, please choose:

- Wandern, Joggen oder Radfahren Hiking, running or cycling
- Wildtiere beobachten watching wild animals
- Pilze, Wildkräuter oder Beeren sammeln collecting mushrooms, wild herbs or berries
- Motorrad- oder Autofahren Motorcycling or driving
- Angeln oder Jagen Fishing or hunting
- andere: something else_____

Page Break

Q2.4 Haben Sie beruflich mit Natur und Landschaft in Bayern zu tun?
Are you professionally involved with activities related to nature and the landscape in Bavaria?

- ja, hauptberuflich yes, full-time job
- ja, nebenberuflich yes, part-time job
- nein no
- weiss nicht don't know

Q2.5 Wenn ja, um welche berufliche Tätigkeit handelt es sich?
If yes, please choose

- ○ Landwirtschaft Agriculture
- ○ Landwirtschaftsberater Agricultural advisor
- ○ Forstwirtschaft Forestry
- ○ Wasserwirtschaft Water resources management
- ○ Umwelt/Geo/Biowissenschaft Environmental-/Geo-/Biosciences
- ○ Naturschutzverband Nature conservation organization
- ○ FischereiFishing
- ○ Behörde (z.B. im Bereich Umwelt, Forst, Agrar, Wasser) Administration (e.g. in the sectors environment, forestry, agriculture, water)
- ○ Imkerei Beekeeping
- ○ Gartenbau Horticulture
- ○ andere: something else:_____

Q3.1 Haben Sie schon mal den Begriff Ökosystemleistungen gehört?
Have you ever heard of the term Ecosystem Services?

- ○ Ja Yes
- ○ Nein No

Q3.2 Wenn ja, aus welcher Quelle?
If yes, from what source?

Q3.3 Was stellen Sie sich unter Ökosystemleistungen vor?
What do you imagine Ecosystem Services to be?

_____

Q9.6 Für wie geeignet halten Sie **Dauergrünland** (Wiesen und Weiden) für die Erbringung der folgenden Leistungen im Ammereinzugsgebiet?
How suitable do you perceive permanent grasslands (meadows and pastures) to provide the following ecosystem services in the Ammer catchment:

Sehr ungeeignet (- -)	Ungeeignet (-)	Weder ungeeignet noch geeignet (- / +)	Geeignet (+)	Sehr geeignet (+ +)	Ist mir unbekannt (?)
Very unsuitable	Unsuitable	Either/ or	suitable	Very suitable	Unknown

Produktion von Tierfutter im Dauergrünland (z.B. Grassilage, Heu)
Production of animal fodder (e.g. grass silage, hay)
Tierproduktion im Freiland (z.B. Milchkühe und Ochsenmast auf Weiden)
Animal production on open land (e.g. dairy cows on pastures)
Produktion von Energiepflanzen im Dauergrünland (Grassilage für Biogasananlagen)
Production of energy by plants on permanent grassland (grass silage for biogas plants)
Erhalt der Bodenfruchtbarkeit (durch natürliche Bodenprozesse)
Retention of soil fertility (by natural soil processes)
Schutz der Grundwasserqualität (durch Stickstoffrückhalt in der Vegetation)
Protection of ground water quality (through nitrogen retention in the vegetation)
Regulation des globalen Klimas (durch Aufnahme von Klimagasen wie CO2 und Speicherung in Böden und Vegetation)
Regulation of the global climate (by uptake of climate gasses such as CO2 and storing insoils and vegetation)
Minderung der Wassererosion (durch Vegetationsdecke)
Reduction of water erosion (through vegetation)
Hochwasserschutz (durch Retentionsflächen in Auenbereichen)
Flood risk reduction (by retention in riparian areas)
Bestäubung von Kulturpflanzen (durch wildlebende Insekten)
Pollination of cultural plants (by wild insects)
Biologische Schädlingskontrolle (durch wildlebende Insekten und Vögel)
Biological pest control (by wild insects and birds)
Erholung in der freien Landschaft (durch Naturerleben und Landschaftästhetik)
Recreation in the open land (by experiencing nature and landscape aesthetics)

Q13.1 Welches Geschlecht haben Sie?
What is your gender?

- ○ männlich male
- ○ weiblich female
- ○ keine Angaben no answer

Q13.2 Welcher Alterskategorie gehören Sie an?
What age category do you belong to?

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- o 18-25
- o 26-30
- o 31-35
- o 36-40
- o 41-45
- o 46-50
- o 51-55
- o 56-60
- o 61-65
- o 66-79
- o > 70

Q13.3 Welchen höchste allgemeine Schulausbildung haben Sie?
What is your highest level of general education you attended?

- ○ Haupt-(Volks-)schulabschluss Lower secondary education
- ○ Abschluss der polytechnischen Oberschule Middle secondary education
- ○ Realschul- oder gleichwertiger Abschluss Middle secondary education
- ○ Fachhochschul- oder Hochschulreife Higher secondary education / University entrance qualification
- ○ Ohne allgemeinen Schulabschluss No school diploma
- ○ Keine Angabe No answer

PAPER II

Plural valuation in space: Mapping values of grasslands and their ecosystem services

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RESEARCH

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Plural valuation in space: mapping values of grasslands and their ecosystem services

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ABSTRACT

The agricultural management of grasslands not only is strongly linked to fodder production but also provides other valuable ecosystem services such as carbon sequestration, nutrient regulation, and recreation. Capturing the values that society places on such ecosystem services is a step to provide management recommendations. To elicit the societal value of grasslands and their ecosystem services, it is important to consider multiple dimensions, namely, instrumental, intrinsic, and relational values. We conducted surveys with citizens in 2018 and 2020 in two study areas in Bavaria, Germany: one grassland-dominated and one with mixed agricultural land use. In the surveys, the respondents were invited to map up to seven points in their respective regions where they perceived grasslands to be 'especially valuable'. Also, the respondents could provide reasons for this selection. These verbatims were classified into instrumental, intrinsic, and several sub-types of relational values using Qualitative Content Analysis. Next, we conducted a hotspot analysis that revealed spatial hotspots and coldspots for each value type . Besides some overlaps, we found that hotspots of instrumental, intrinsic, and relational values varied in space. A Constrained Correspondence Analysis underlined the trade-offs between instrumentally valued grasslands that are perceived as suitable to supply provisioning services and intrinsically valued grasslands that are closely related to relational values such as care. The results show that grasslands and their ecosystem services are valued for a variety of reasons on different locations, and point out the need for further investigations of the spatial distribution of values associated with ecosystem services.

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Grasslands; hotspots; sociocultural valuation; relational values; spatial valuation

1 Introduction

Ecosystems and their services are declining at alarming rates globally (IPBES, 2019). Human decisions and resulting behavior heavily influence the ability of ecosystems to provide such ecosystem services (Daily et al. 2009; Díaz et al. 2015). These decisions are also influenced by the multiple ways in which nature, ecosystems, or ecosystem services are valued by people (Díaz et al. 2015; Pascual et al. 2017; Arias-Arévalo et al. 2018). Besides decisions taken by land managers that directly affect the supply of ecosystem services incorporating citizens' values in future land use decisions can be very important for policy- and decision-making that leads to sustainable outcomes (Harmáčková et al. 2021). For example policy-making processes in the EU that incorporate values of citizens have been identified to be increasingly important for setting up land-use policies (Newig and Koontz 2014).

Values are understood here as the 'importance, worth or usefulness' of nature and ecosystem services to people (Díaz et al. 2015; Pascual et al. 2017). One person can hold multiple diverse values associated with ecosystem services, but differences can also occur between societal actors (e.g. Arias-Arévalo et al. 2017; Martín-López 2021). It is important to understand, acknowledge, and address this diversity of values to foster sustainable outcomes (Pascual et al. 2017; Jacobs et al. 2020; Zafra-Calvo et al. 2020). While the need for plural valuation moving beyond merely monetary value metrics has received widespread attention (e.g. Jacobs et al. 2016 2018; Pascual et al. 2017; Arias-Arévalo et al. 2018) different approaches to integrating multiple values are still under development. For example, Muradian and Pascual (2018) suggest to use a typology of human-nature relations for taking into account the diversity of values that underlie individual and social behavior. Additionally Jacobs et al. (2018) provide a comprehensive review of valuation methods and their capacity to elicit multiple values of nature.

Following the recent valuation guidelines developed by the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services

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(IPBES), we differentiate in this study between instrumental, intrinsic, and relational values (Díaz et al. 2015; Pascual et al. 2017). While intrinsic values are considered independent of any human experience and refer to the inherent value of nature and ecosystem services as end in itself instrumental and relational values are human-driven (Díaz et al. 2015). Instrumental values represent the direct and indirect benefits people obtain from ecosystem services and relational values link to the meaningfulness of relationships such as those among people and between people and nature (Chan et al. 2016; Pascual et al. 2017; Schröter et al. 2020). Because instrumental values refer to the importance of nature and ecosystem services as a means to an end, they implicitly involve substitutability (Arias-Arévalo et al. 2018). As an example, Martín-López (2021) refers to the instrumental value of an apple tree 'as a means to achieve a certain amount and quality of apples'. The instrumental value of an apple tree may then be replaced by the same number of apples with similar quality provided by a supermarket. Framing the importance of an apple tree in instrumental terms might overlook the many ways that farmers might relate to that particular apple tree and the orchard. As the relationships among humans and between humans and nature can be diverse several sub-types of relational values exist, such as a feeling of belonging and sense of place, sense of agency, social cohesion, or appreciation of recreation in nature (Arias-Arévalo et al. 2018; Riechers et al. 2021).

In order to elicit plural values of ecosystem services, including intrinsic, instrumental, and relational values, plural valuation approaches are needed (Jacobs et al. 2016; Pascual et al. 2017). However plural valuation of ecosystem services is still in its infancy (Jacobs et al. 2018; Christie et al. 2019). This is particularly true for agro-ecosystems where monetary valuation techniques have been mostly used to elicit instrumental values of ecosystem services (Nieto-Romero et al. 2014). Yet many studies agree that plural valuation exercises that include relational values are vital to capture additional reasons by which people express the importance of nature and ecosystem services (e.g. Chan et al. 2016; Arias-Arévalo et al. 2017, 2018; Klain et al. 2017; Himes and Muraca 2018). For example in agricultural landscapes, Chapman (2019) found that including farmers' relational values in the design of agro-environmental incentive programs can increase enrolment rates and foster conservation stewardship. In the Cape Floristic Region Topp et al. (2021) found that when farmers endorse plural values including several relational values, the decision-making regarding the management of the farm might lead to more ecosystem services.

In agricultural landscapes, grasslands provide a variety of ecosystem services depending on their management regime and intensity (Le Clec'h et al. 2019). Grasslands of low management intensity characterized as hotspots of biodiversity, are highly threatened due to abandonment, afforestation, and transformation into crop fields (Habel et al. 2013). Notably grasslands remain one of the most understudied ecosystems in ecosystem services research (Bengtsson et al. 2019; Zhao et al. 2020) and have mainly been studied from the biophysical perspective i.e. the capacity of biodiversity to provide services (e.g., Crouzat et al. 2015; Schirpke et al. 2016; Le Clec'h et al. 2019). In fact assessments concerning socioeconomic aspects of ecosystem services in grasslands, such as social perceptions, demand, and values, still remain elusive (Zhao et al. 2020). In contrast to values perceptions of ecosystem services can be loosely defined as a way of observation, understanding, interpretation, and evaluation (Bennett 2016). Yet few studies have explored social perceptions of ecosystem services provided by grasslands. For example, Schmitt et al. (2021) found that most ecosystem services provided by grasslands were perceived as highly important in farmers' management considerations in (pre-)Alpine grasslands. Also Pachoud et al. (2020) found that most ecosystem services of Alpine summer farms are positively perceived by visitors. Despite this recent sociocultural research plural valuation of ecosystem services in grasslands where relational, intrinsic, and instrumental values are included is still in its infancy.

Values of ecosystem services vary in terms of their spatial distribution due to geographical, biophysical, and accessibility factors (Fagerholm et al. 2019). Thus a focus on place when assessing values can reveal connections between people and their biophysical surroundings (Fagerholm et al. 2012, 2019) and can help to inform land managers and decision-makers about areas of high and low value (e.g. Karimi et al. 2020). This can be crucial for landscape management (De Vreese et al. 2016) as well as to identify land use conflict potential (Brown and Raymond 2014; Brown and Fagerholm 2015) as space needs to be recognized as the product of the interrelations between humans and nature (Massey 2005). The use of public participation GIS and participatory GIS has frequently been applied to capture the spatial allocation of values (Brown and Fagerholm 2015). A prominent example of participatory mapping techniques is the GIS application of Social Values for Ecosystem Services (SolVES) developed by Sherrouse et al. (2011) to quantitatively assess, map, and quantify social values of ecosystem services. However, uncovering relational values often requires qualitative methods for data collection, such as interviews, in order to allow social

actors to express their real connections with nature and ecosystem services (Stålhammar and Thorén 2019). In this study we apply a mixed-method approach, including qualitative and quantitative data collection and analytical techniques.

With an analysis of the spatial distribution of intrinsic, relational, and instrumental values of ecosystem services provided by grasslands, we aim to shed further light on the trade-offs and synergies between values in a spatial context. We specifically aim to (1) elicit and map instrumental, intrinsic, and relational values of grasslands and their ecosystem services; (2) spatially assess the trade-offs and synergies that might exist between values and (3) analyze the associations between values, perceptions of ecosystem services, and sociodemographic characteristics.

2 Methods

2.1 Study areas and characteristics

We conducted this research in two study areas in Bavaria (Germany) to represent two different agricultural systems in Central Europe, namely the grassland-dominated (pre-)Alpine Ammer study area and the Red and White Main (RWMain) study area (Figure 1) which is characterized by mixed agricultural land use. We chose to conduct the surveys in different study areas to compare two typical landscapes, one dominated with grassland and the other with a mixed cropland–grassland ratio.

The Ammer study area entails the catchment of the river Ammer and parts of the Isar, Lech, and Loisach catchments. The pre-Alpine and Alpine environments consist of 36% agricultural land, 41% forest patches, 5% water bodies, 4% human settlements, and 14% other land cover including mountainous rock and peat environments. This area's unique characteristic is its dominance of grasslands in the agricultural sector consisting of 71% of the agricultural land use (LDBV, 2016). A gradient of intensity from north to south characterizes the study area. In the northern part approximately 50% of the agricultural land use is grassland-based (County Starnberg), and in the south, grasslands dominate agricultural land use with 99% (County Garmisch-Partenkirchen). Specifically, in the southern, Alpine part, very extensively managed grasslands are still present. These include traditional humpback meadows (*Buckelwiesen*) and Alpine summer pastures (*Almen*). The north to south gradient is also visible in topography. It ranges from the hilly pre-Alpine northern part to the Ammergau Alps, Bavarian Prealps, and Wetterstein mountains in the south, including Germany's highest peak, 'Zugspitze' with an altitude of 2,969 m.a.s.l (NASA, 2009). The largest towns in the Ammer study area are Garmisch-Partenkirchen (pop. 27000) and Weilheim (pop. 23,000). In the northern counties Weilheim-Schongau and Landsberg, the primary and secondary economic sectors are highly important, due to the prominence of agricultural activities and the proximity to Munich in the north. In the southern county Garmisch-Partenkirchen, characterized by the Alpine environment, tourism takes a high stake leading to a very high importance of the service industry (Table B1). The study area is located within the European Metropolitan Area of Munich. With the Ammer Alps Nature Park (IUCN category V), the study area includes a protected area that targets to conserve

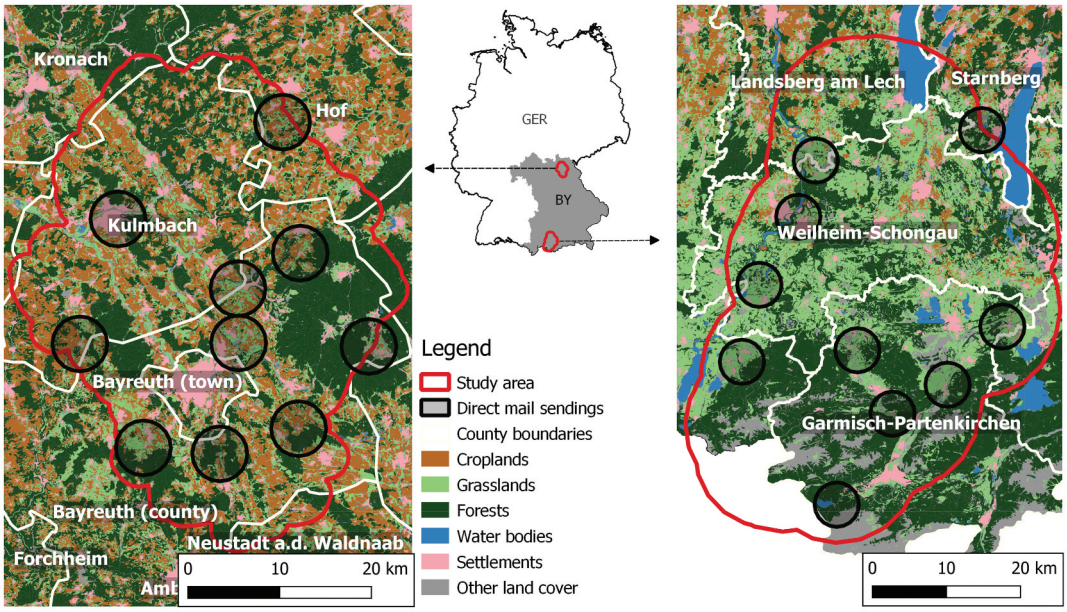

Figure 1. Location and characteristics of the RWMain study area (left) and the Ammer study area (right) in Bavaria (BY), Germany (GER).

nature by supporting its utilization through sustainable land use practices and recreational activities.

The study area along the Red and White Main catchment (RWMain) entails parts of the catchments of the Saale, Naab, Eger, and Regnitz rivers. The two separate streams Red Main and White Main confluence in the northwest of the study area marking the start of the river Main, one of Germany's major streams. The region is characterized by mid-altitude mountain ranges, including the Fichtel Mountains (*Fichtelgebirge*) in the east, Franconian Switzerland (*Fränkische Schweiz*) in the west, and the Franconian Forest (*Frankenwald*) in the north (see Figure A1). These three regions are also classified as Nature Parks (IUCN category V). The study area consists of 41% agricultural land, 42% forest patches, 7% human settlements, and 10% other land covers including rock environments and human infrastructure. The agricultural land use is mixed and consists of approximately 40% grasslands. In the counties of Bayreuth and Kulmbach, the primary and secondary sectors are economically important, while in the town of Bayreuth, most employment takes place in the service industry (Table B1). The highest peak of Northern Bavaria, 'Schneeberg', (1051 m.a.s.l.) is in the Fichtel Mountains. The largest towns in the study area are Bayreuth (pop. 74,000) and Kulmbach (pop. 26,000). The study area is located within the European Metropolitan Area of Nuremberg. The home institution of some authors is in Bayreuth, located in the RWMain study area.

2.2 Data collection and sample characteristics

We conducted surveys with citizens living in the Ammer and RWMain study areas in 2018 and 2020. We chose these years to test potential bias towards distinct events. For example, the surveys 2020 might have been influenced by the Covid-19 pandemic that impacted activities of citizens in nature (Schweizer et al. 2021). Also a Bavarian referendum that included legal changes in agriculture took place in 2019. As many of these changes intended to increase biodiversity-friendly farming focused on grassland management and preservation (Hartmann et al. 2021) the referendum had the potential to influence the values of ecosystem services expressed by the respondents.

Households located in a 3 km radius of 20 randomly selected points received an invitation card to participate in the online survey (Figure 1). We provided a link and a QR code in the postal cards to the online survey that could be filled out on any electronic device with internet connection. We slightly modified the final centroids of the circles from the random allocation in areas of very low population (Figure A2). In total 79,313 invitations were sent via direct mail by the German Federal Post Office from which 1139 respondents at least partially filled out the survey. All surveys were conducted anonymously and analyzed separately from any personal data (optionally provided). We pre-tested the questionnaire in the pedestrian zone of Garmisch-Partenkirchen prior to the execution of the study by conducting 188 questionnaires in spring 2018.

The surveys covered the theme 'Agriculture, Climate Change, and Nature Conservation'. Alongside other questions related to ecosystem services provided by grasslands, we asked participants to indicate on a map of their respective regions up to seven points where they perceive grasslands to be especially valuable. In total, 627 respondents mapped 3645 points. The map was not scalable or zoomable to ensure a uniform map size for all respondents. After mapping each point, an open question followed in which respondents indicated the reason why they perceive these grasslands as valuable. This open question was used to infer values that the respondents attached to the grasslands. The response rate of this question out of all respondents that at least partially filled out the survey (1139) was 45% (515 responses). In addition, to explore social perceptions of ecosystem services, we asked citizens to rate on a 5-point Likert scale how suitable they perceive grasslands for the supply of certain ecosystem services, namely, fodder production, animal production, energy plant production, soil fertility, groundwater quality, climate regulation, soil erosion reduction, flood risk reduction, pollination, biological pest control, and recreation. In this study, we understand perceptions as a way of observing, understanding, interpreting, and evaluating the capacity of grasslands to supply ecosystem services (Schmitt et al. 2021). The selection of ecosystem services was based on expert knowledge on relevant grassland ecosystem services (see Schmitt et al. 2021). The questionnaire also included sociodemographic characteristics of respondents and the private activities they frequently do in nature (see Table B1 and C1 in the Supplementary Material).

2.3 Data analysis

2.3.1. Elicitation of values: content analysis and statistical analysis

First, we conducted a Qualitative Content Analysis (QCA) with MaxQDA Plus 2020 (Release 20.4.0) to code the reasons why respondents consider the mapped grasslands as valuable. These reasons given, also referred to as verbatims, were coded according to the classification of intrinsic, relational, and instrumental values following Arias-Arévalo et al. (2018) and Pascual et al. (2017). Since the notion of intrinsic value is considered independent of human experience and therefore valuation (Díaz et al. 2015) we

considered the 'subjective' intrinsic value as suggested by O'Connor and Kenter (2019). The elicitation of 'subjective' intrinsic value is based on the idea that humans can express regard for biodiversity and ecosystem services independent of human interest (O'Connor and Kenter 2019).

Responses that could not be clearly attributed to a value category were discarded. Here, it is important to note that intrinsic, instrumental and relational values are connected and might be simultaneously present when respondents articulate why grasslands matter to them. For example, Arias-Arévalo et al. (2017) show such an interaction with the verbatim '(the Otún watershed) is indispensable for life on the planet [*intrinsic value*]. Having good-quality water ensures a good health and good quality of life [*relational and instrumental values*]'. Therefore when respondents expressed the importance of grasslands, they might refer to the three categories of values.

In addition, concerning relational values, we coded them in different relational value sub-types since the emergence of the articulated values resulting from the relationship humans have with nature can be manifold. For coding relational values, we followed the classification provided by Arias-Arévalo et al. (2018). In this case we are aware that a particular statement can refer to different relational values as they can be strongly intertwined. For example, the verbatim *'[. . .] I explored these areas already 60 years ago with my father [. . .] (2,020,361)'* refers to the relational value 'social relations' (see Table 1) but it can be also interpreted as 'cultural heritage' when the statement adds some nuances regarding traditional knowledge or traditions. In addition, we only considered relational value sub-types that were mentioned more than ten times for further statistical analysis (see Table 2). We also conducted a hierarchical cluster analysis for the articulated relational values in order to combine them for the mapping exercise and further statistical analysis using the R package *FactoMineR* (Husson et al. 2020).

The coding was a reiterated process that involved two rounds of internal review by all authors (see Table 1 for examples). We could allocate at least one value to the statements of 304 respondents out of the 515 respondents to the question.

Finally, we conducted the Mann-Whitney-U-Test for each value domain to explore differences of the articulated values between the study areas and over time. For the statistical analysis and data processing, we used RStudio Version 1.3 and R Version 4.0.2 (RStudio 2020).

2.3.2. Mapping values: Getis-Ord Gi* hotspot analysis

We applied Getis-Ord Gi* statistics (Getis and Ord 1992) for each articulated value to uncover spatial clusters of grassland locations where the respective values prevail. We employed Getis-Ord Gi* hotspot analysis as frequently used in the study of ecosystem services' hotspots (Brown and Raymond 2014). The hot- and coldspots revealed using this method represent a spatial cluster of points associated with the respective values more frequently than by random choice within the context of neighboring points. Hotspots (and coldspots) can be defined as an area where a variable in our case value prominence, is significantly higher (or lower) than average in the study area. The delineation is based on the Getis-Ord Gi* statistics that considers not only the value of each point, but also of surrounding points. This local sum must be significantly higher (or lower) than the expected local sum based on all features in the study area (Getis and Ord 1992). We conducted the analysis in ArcGIS 10.7.1. Getis-Ord Gi* offers several advantages over other density maps or spatial clustering methods such as being able to differentiate hotspots and coldspots of high and low values (Zhu et al. 2010). Bagstad et al. (2017) suggest that Getis-Ord Gi* can provide useful results for ecosystem service hot-/coldspots mapping to inform landscape-scale planning. For this analysis we joined the coded articulated value(s) (see 2.3.1) to all points marked by the respective respondent to be valuable grasslands (see 2.2). Unless respondents differentiated values for specific grassland locations, we assume that articulated values per respondent apply to all marked grassland locations by the respective respondent. For each value, the points were coded as '1' if the respondents articulated the respective value and '0' if not. We only considered points mapped by respondents who expressed at least one value (304 participants indicated values and mapped 1656 points).

2.3.3. Associations between values, ecosystem service perceptions and sociodemographic characteristics: constrained correspondence analysis

We conducted a Constrained Correspondence Analysis (CCA), a multivariate ordination technique frequently used to explain patterns in sociocultural valuation of ecosystem services, by relating perceptions to potential predictors (e.g. Casado-Arzuaga et al. 2013; Al-assaf et al. 2014; Morales-Reyes et al. 2018). We related the values that respondents associated with grasslands to respondents' characteristics (age gender, education level, employment in a job related to nature, and private activities in nature) and ecosystem service perceptions (Likert-based ratings of the perceived suitability of grasslands to supply certain ecosystem services). A Monte Carlo permutation test (999 permutations) was used to identify the significance of the model. We used the R package vegan v. 2.4. for this analysis (Oksanen et al. 2020)

Table 1. Value types, sub-types of values, description (modified from Arias-Arévalo et al. (2018)), times the value was stated (n) and a translated example from the coded dataset. Respondent IDs are reported in brackets. ES: Ecosystem services.

Value types	Value sub-type	Value description	n	Illustrative examples
Instrumental		Direct or indirect monetary benefit; utility	20	*'Easily economically usable (location, field size) (2,020,302)'* *'Size of the area and proximity to consumers (2,020,286)'*
'Subjective' intrinsic		Nature's right to exist	121	*'In my experience these are important places where wild plants or wild animals exist that should simply be further protected (2,020,438)'* *'Especially along lakes and rivers we need large amounts of grasslands as many animals live close to waters, give birth and raise their offspring (2,018,327)'*
Relational	Security	ES critical for achieving security including meaningful livelihood, energy and health goals	14	*'I am convinced that untouched grasslands are important for clean drinking water [. . .] (2,020,376)'*
	Ecological resilience	Capacity of ecosystems to maintain their integrity in the face of disturbances (e.g. prevention of hazards such as flooding)	23	*'Notable landscapes with an intact ecosystem and rare plants and animals. The conservation of these is important for a stable system in the pre-Alpine region (2,018,281)'*
	Mental and physical health	Physical benefits perceived from ecosystems' regulation of water, air and diseases, and mental benefits due to exposure to nature	7	*'It has stress-reducing effects (2,018,526)'*
	Sense of place	Emotional attachment to a place/feelings of belonging, commitment, identity or community (e.g. notions of 'home' or attributes to locations signaling feelings of belong such as 'my surroundings')	39	*'It is just typical Bavaria, I got to know it like this as a child and kept it in my memories. This is why I moved back here after my studies in Baden-Württemberg (2,018,277)'*
	Cultural heritage	Tangible and intangible features of landscapes which are historically significant (e.g. buildings, monuments, traditions, stories, traditional ecological knowledge, other knowledge systems)	6	*'I am a farmer and an "Alpler" (herdsman) in the Ammer mountains and would like to continue to manage it as I always have. The Ammer mountains are so beautiful due to the management, so we do not need a change (2,020,335)'*
	Aesthetic	Appreciation of the beauty of nature, grounded on sensations and emotions	39	*'Personal connection to beautiful landscape (2,020,327)'*
	Recreational	Appreciation of tourism, recreational and leisure activities in natural areas	60	*'The grasslands towards Unternogg/Halbammer are a beautiful place for recreation for my family and me (2,020,159)'*
	Cognitive Development	Appreciation of ecosystems' features within special educational and scientific interest	3	*'The River Lech runs through our town and there is still quite some valuable nature that is taught to us by Lech Rangers (2,025,252)'*
	Care	Core values about nature as related to universal moral values such as care, responsibility and stewardship towards nature, landscape and land (e.g. motions of "we should protect	92	*'[. . .] Here we should protect and use nature, not interfere with it (2,020,230)'*
	Social relations/ cohesion	Nature as a platform where social relationships are fostered	1	*'[. . .] I explored these areas already 60 years ago with my father [. . .] (2,020,361)'*
	Altruism	Concern for biodiversity, ecosystems or ES in favor of a present larger community of (future) generations	14	*'As close to towns as possible so that people who are not mobile are close to grasslands (2,020,436)'*
	Meaningful occupation	Occupations related to biodiversity and ecosystems that allow people to fulfill a good human life	1	*'[. . .] I think that the farmers are doing very responsible great work for uncountable years!! [. . .] (2,020,577)'*

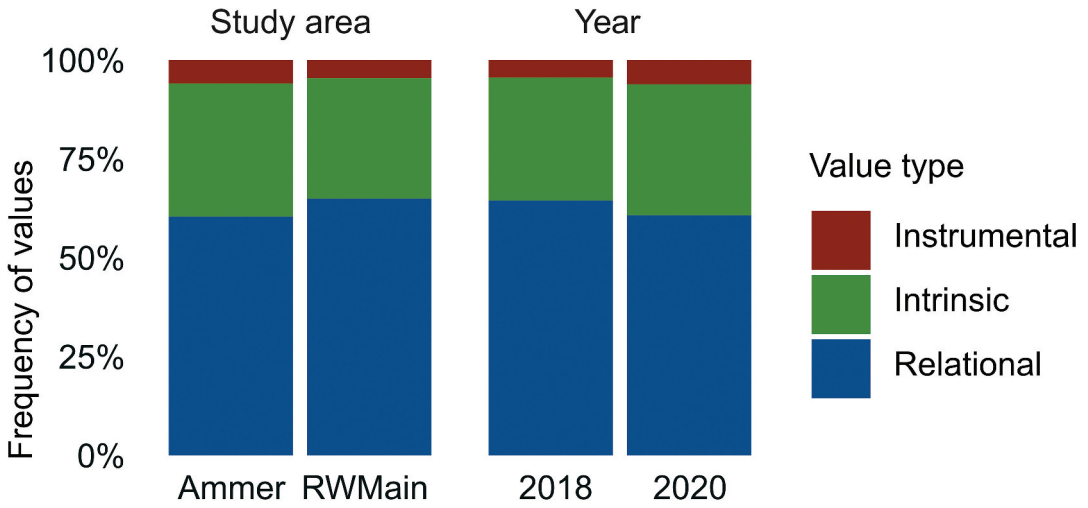

Figure 2. Frequency (in %) of respondents (n = 304) that expressed instrumental, intrinsic, or relational values. Per respondent, only one count per value type is included in this figure, even if a value type was indicated multiple times by the same respondent.

3 Results

3.1 Values associated with grasslands

Respondents referred to various values when they explained why certain grasslands are important to them, including instrumental, 'subjective' intrinsic and relational values (Table 1). Out of the 304 respondents who indicated at least one value relational values were the most frequently expressed (62.5% of the respondents), followed by 'subjective' intrinsic values (32.2%) and instrumental values (5.3%). We did not find statistical differences in articulated values between study areas and between 2018 and 2020 with the Mann-WhitneyU-Test (Figure 2; Table D2).

We identified 12 different articulated sub-types of values in the domain of relational values. Seven sub-types were mentioned more than ten times (Table 1). The hierarchical clustering revealed five groups of relational values: namely aesthetics, care, recreation, sense of place, and a cluster consisting of ecological resilience, security, and altruism (Table 2; Figure D1). We found statistically significant differences between the two study areas for the articulated relational values of care and recreation (Table D3). As shown in Table 2 respondents indicated recreational values more often in the RWMain study area than in the Ammer study area. Care was mentioned significantly more often in the Ammer study area than in the RWMain study area. We did not find significant differences in the articulated relational values between 2018 and 2020.

3.2. Spatial hotspots of values associated with grasslands

The Getis-Ord Gi* Hotspot Analysis indicated distinct hotspots and coldspots of articulated values in both study areas (Figure 3). In the Ammer study area hotspots of grasslands associated with instrumental values were clustered along the river Lech in the western part of the study area and coldspots were located around the Murnau peatlands in the southeast of the study area (see Figure A1 for geographical features). The opposite pattern emerged for hotspots of 'subjective' intrinsic values. These were located in the east of the study area, specifically along the Murnau peatlands and the southern, mountainous part of the study area, and the drainage into Lake Starnberg. In the RWMain study area, this opposing pattern is less distinct, but still visible. Hotspots of instrumental values are clustered in the east and southeast of Bayreuth and north of the Fichtel Mountains. Hotspots of 'subjective' intrinsic values were revealed along the River Red Main, surrounding

Table 2. Differences in relational articulated values between regions and years; ** indicates statistically significant results at $p < 0.05$; * indicates significance at $p < 0.10$.

Relational value subtype	Total	Study area			Year	
		Ammer	RWMain		2018	2020
Aesthetic	39	24	15		24	15
Care	92	56	36	*	45	47
Recreation	60	24	36	**	26	34
Sense of place	39	18	21		18	21
Altruism, security, ecological resilience	47	20	27		21	26

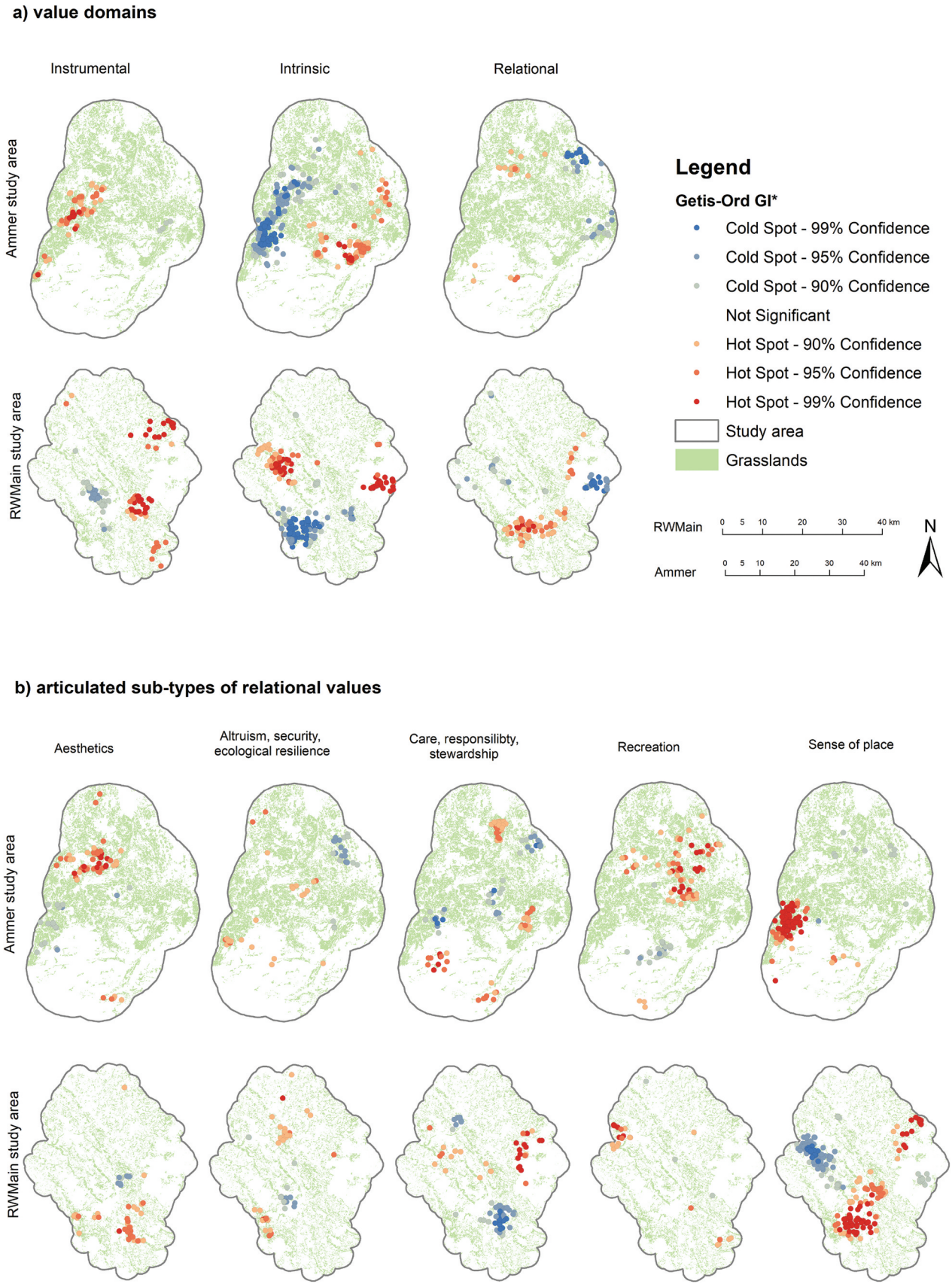

Figure 3. Getis-Ord Gi* hot- and coldspots (dots) of (a) value domains (Instrumental, 'subjective' intrinsic, relational) and (b) articulated sub-types of relational values associated with grasslands in the Ammer (top) and RWMain (bottom) study areas.

the conjunction of the Red Main and White Main streams, and in the Fichtel Mountains.

Concerning relational values, we also found spatial patterns according to the value sub-type. Some articulated relational values are strongly clustered in space (e.g. sense of place), while others are more widely spread out throughout the study area (e.g. altruism, security, and ecological resilience).

Hotspots of sense of place overlap with hotspots of instrumental values in the southwest of the Ammer study area along the river Lech, in the RWMain study area north of the Fichtel Mountains and in the southwest. The hotspots of the relational value of care are, similar to hotspots of 'subjective' intrinsic value, located in prominent natural areas, such as the Murnau peatlands, estuaries of lake Ammer and the Alps in the Ammer study area. In the RWMain study area, hotspots of care are in the conjunction of the streams Red and White Main as well as the Fichtel Mountains. Interestingly, the hotspots located in the Fichtel Mountains overlap not only with 'subjective' intrinsic hotspots in the center of the natural park, but also with instrumental values in the north of the park. Prominent overlaps also exist between hotspots of recreational and aesthetic values in both study areas (Figure 3).

3.3 Connections between values, perceptions of ecosystem services, and sociodemographic characteristics

The Constrained Correspondence Analysis (CCA) indicated a statistically significant association between certain values attached to specific grasslands, perceptions on the suitability of grasslands to supply ecosystem services, and sociodemographic characteristics ($p = 0.013$ with 999 permutations; Figure 4). Axis 1 (30.14%) of the CCA showed in the negative scores an association between citizens that indicated instrumental value as well as sense of place and aesthetics and those citizens that perceived grasslands as very suitable to supply provisioning (fodder production animal production, energy plant production) and some regulating services (pollination, climate regulation, groundwater regulation). Male citizens most often expressed these instrumental values. In the positive scores of Axis 1, elderly people, higher educated respondents, citizens who enjoy nature for various private activities (go hiking, running, or cycling, observe wild animals, and collect wild berries and herbs) and those citizens who perceive flood risk reduction and soil erosion reduction as particularly suitable to be supplied by grasslands expressed 'subjective' intrinsic values as well as the relational values of care, recreation, and security, altruism, and ecological resilience.

Scores of Axis 2 (22.05%) revealed differences between people who are employed in a nature-related job and people who rated ecosystem services

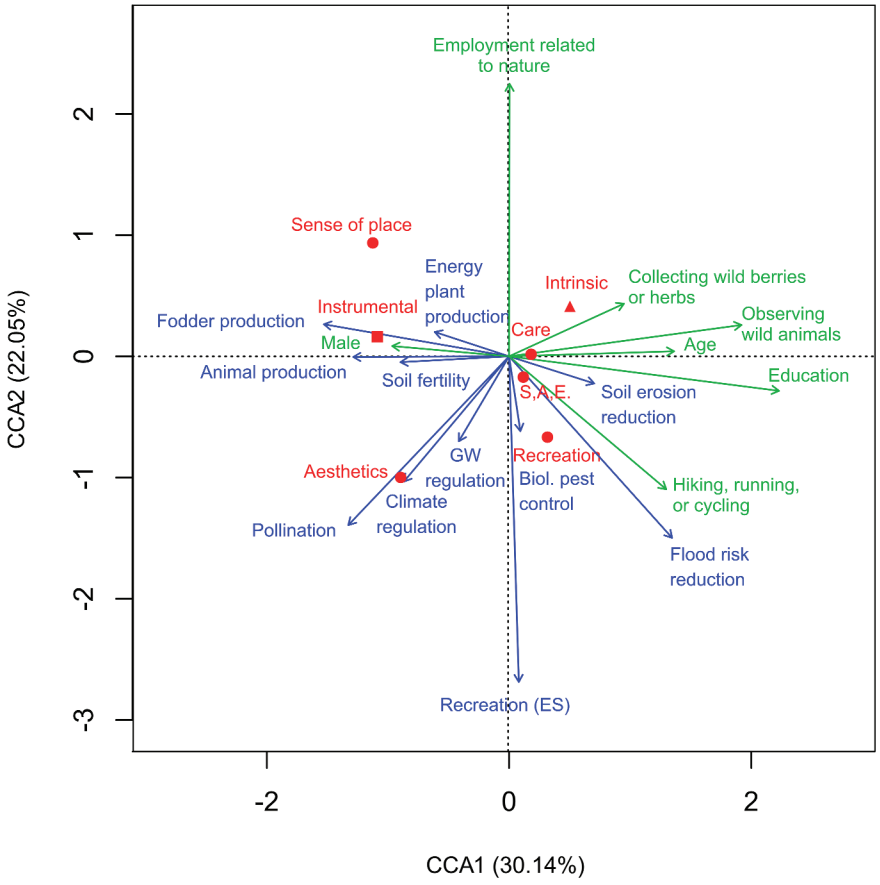

Figure 4. Constrained correspondence analysis indicating the connections between intrinsic (red triangle), instrumental (red square), and relational (red circles) values associated with grasslands, the perceptions of ecosystem services (blue), and further personal characteristics (green). (S,A,E = Security, Altruism, Ecological Resilience; Biol. pest control = Biological pest control; GW regulation = Groundwater regulation).

Table 3. Results of the first two axes of the CCA.

	Axis 1	Axis 2
Eigenvalue	0.137	0.084
Proportion explained (%)	33.5	20.7
Cumulative proportion explained (%)	33.5	54.2

as particularly suitable to supply recreational ecosystem services. This axis did not present major associations of sociodemographic characteristics and perceptions on the suitability of grasslands to supply ecosystem services with values. In total, however, only 54% of the variance could be explained (Table 3).

4 Discussion

The goal of this study was to gain further insights into the values that citizens associate with grasslands and how these vary in space. We also aimed to identify the connections between values of grasslands, perceived suitability of grasslands to supply certain ecosystem services, and sociodemographic characteristics. In the following, we firstly discuss the social and spatial trade-offs and synergies concerning values attached to grasslands. Next, we show the importance of studying the spatial dimension of plural valuation for management recommendations. Finally, we draw attention to methodological limitations of the study.

4.1 High societal value of grasslands: distribution of 'subjective' intrinsic, instrumental, and relational values

The results of the Qualitative Content Analysis (QCA) revealed a wide range of values that citizens associated with grasslands. Overall, relational values resonated more frequently than instrumental or 'subjective' intrinsic values in our study. The high occurrence of relational values illustrates, that, besides the utilitarian purpose of grasslands to supply fodder and its 'subjective' intrinsic value of biodiversity, there is a need to acknowledge the complex, non-substitutable relationships between nature and people (Himes and Muraca 2018). The high tally of relational values corresponds with the findings of previous research in other contexts. Arias-Arévalo et al. (2017) for example, found in a study on values associated with nature in the central Colombian Andes a likewise low amount of people who valued nature for purely instrumental reasons while the majority of respondents indicated relational values. Similarly, in a study on values, rules, and knowledge in the Cape Floristic Region, Topp et al. (2021) found that farmers articulated relational values much more frequently than instrumental and 'subjective' intrinsic values. In a quantitative questionnaire-based study in Guanacaste, Costa Rica, Klain et al. (2017) found very high agreements with relational value statements from farmers, residents, and tourists. Among relational values, we found that care was the most important relational value expressed by respondents (Table 2). Klain et al. (2017) also found that the level of agreement for the statement associated with the notion of care responsibility and stewardship towards nature was higher than the ones referring to other relational values.

Besides the very high amount of verbatims associated with relational values, we found a proportionally larger number of statements attributed to 'subjective' intrinsic values than previous research (Arias-Arévalo et al. 2017; Topp et al. 2021). A potential reason for this might be the overall high biodiversity of grasslands compared to other agricultural land use especially grasslands of low management intensity (Marini et al. 2007; Habel et al. 2013). Moreover there is a thin line regarding the attribution of some verbatims to value categories, such as 'subjective' intrinsic and relational values. In fact, the regard expressed by respondents for grasslands independent of human interest, that is 'subjective' intrinsic values, can be also seen as a kind of relational value (O'Connor and Kenter 2019). For example while some studies classified the moral duty towards nature as an intrinsic value (Arias-Arévalo et al. 2017; Coelho-Junior et al. 2021) others considered it as a relational value (Topp et al. 2021). A relational view of intrinsic values is proposed by the value categorization of Muradian and Pascual (2018) suggesting that intrinsic values could indeed be classified as a 'wardship' relational model.

4.2 Dichotomy between instrumental and 'subjective' intrinsic values: the spatial and social trade-offs

Trade-offs between instrumental and 'subjective' intrinsic values, often referred to as a dichotomy, have been extensively described in the scientific literature of nature valuation (Chan et al. 2016; Arias-Arévalo et al. 2018; Himes and Muraca 2018). The results of our study of grasslands support the occurrence of such trade-offs in a spatial context. Hotspots of 'subjective' intrinsic values were located in places of high biodiversity and nature conservation such as the Murnau peatlands and the estuary to Lake Starnberg in the Ammer study area. In the RWMain study area, the Fichtel Mountains as a natural park and the conjunction of the Red and White Main rivers are prominent natural sites that were also

characterized as hotspots of 'subjective' intrinsic values. The coldspots of these 'subjective' intrinsically valued grasslands located along the river Lech in the west and north of the Ammer study area were nearly exclusively mapped to be hotspots of instrumental value. Similarly, in the RWMain study area, there were no overlaps of hotspots of 'subjective' intrinsically and instrumentally valued grasslands. More quantitative GIS-based studies also found differences between 'subjective' intrinsic and tangible values. For instance, in a study on wilderness values in Alaska, Brown and Alessa (2005) found that people placed intrinsic values inside wilderness areas while areas outside of such received more tangible values including immediate economic uses.

The dichotomy between instrumental and 'subjective' intrinsic values can also be observed in the results of the Constrained Correspondence Analysis (CCA). Both value domains are placed on the opposing first axes. Furthermore, instrumental values were closely connected to provisioning services, so citizens who articulated instrumental value also indicated that they perceive grasslands to be very suitable to supply provisioning services. Verbatims such as *'size of the fields and proximity to customers (2,020,286)'* or '*these (grasslands) are easily economically usable (2,020,302)*' show that the perceptions of grasslands as especially suitable to supply provisioning services aligns with the existence of instrumental values. These results imply that agricultural production of food in the study areas is highly connected to utilitarian values of grasslands aiming at economic profit, and less about relational values such as sustaining livelihoods to maintain (food) security. Furthermore, instrumental values were not only associated with agricultural production, but also in combination with tourism, which could explain the close connection on the first axis of the CCA to aesthetics. Grasslands have high aesthetic values, irrespective of whether they are used for fodder production in lower elevations or grazing in higher elevations (Schirpke et al. 2021). Concerning sociodemographic characteristics we found that male respondents were more likely to value grasslands for instrumental reasons and to perceive grasslands to be suitable for the provisioning for fodder and animal production. This supports findings of a review on gender perspectives in ecosystem service research by Yang et al. (2018) that concluded that women had closer connections to certain regulating services and biodiversity while men had more knowledge of provisioning services.

4.3 Relational values acting as a bridge: synergies between values

Besides trade-offs between 'subjective' intrinsic and instrumental values, values are also connected with each other. On the one side, different types of values can overlap in their meanings (Schröter et al. 2020). On the other side different values can be expressed simultaneously by the same respondents (Arias-Arévalo et al. 2017; Himes and Muraca 2018; Martín-López 2021). For instance one citizen in our study expressed that grasslands are *'important for nature, recreation and climate; dairy farming, milk, agriculture (2,020,304)'* exemplifying the multiple values that can simultaneously be associated with grasslands. We also observed several synergies between values on a spatial scale. Here, it becomes prominent that relational values spatially overlap with both instrumental and 'subjective' intrinsic values, acting as a bridge between these contrasting values.

'Subjective' intrinsic values, opposed to instrumental values, show a strong connection to respondents who indicated to privately spend time in nature and are higher educated in the results of the CCA. This pattern aligns with the maps of value hotspots since those places that were hotspots of 'subjective' intrinsic values partially overlapped with those places important for their recreational value (Figure 3; Figure A1). The association between 'subjective' intrinsic values and conducting private activities in nature can be explained because the repetitive act of going to nature to observe wild animals, collect wild berries or go hiking can foster meaningful relationships with nature and a sense of care for nature (i.e. relational values) that with time might lead to the endorsement of moral rights and the recognition of 'subjective' intrinsic values (Martín-López 2021). The emergence of a certain value (e.g. 'subjective' intrinsic) by activities motivated through a different value (e.g. recreation) also exemplifies that values can nurture each other (Chan et al. 2016; Arias-Arévalo et al. 2018). Hence locations in which hotspots of different values were mapped can have a distinct role in fostering other values.

We also found clear spatial overlaps between hotspots of 'subjective' intrinsic values and the relational value of care in both study areas. When care is expressed in terms of biodiversity protection, this connection can be essential for stewardship and conservation activities (West et al. 2018). Caring for nature through policy and management practices, plays a fundamental role regarding stewardship actions and relates to the concept of 'People for Nature and Landscape' (De Vreese et al. 2019). On the contrary we found some overlaps between care and instrumental values in the RWMain study area in the north of the Fichtel Mountains (Figure 3). This interesting result supports recent findings showing that care as a concept can give vital insights into understanding what an area is supposed to be used for and what practices are accepted by society (Jax

et al. 2018). Care in this regard, also illustrates the intermediate position of relational values between 'subjective' intrinsic and instrumental value domains. The reasons why people care for specific grassland areas and take actions to preserve grasslands that sustain specific habitats are manifold in our dataset. Hence, further investigation of what grasslands are being cared for could be very helpful to disentangle the intermediary position of care between instrumental and 'subjective' intrinsic values (Jax et al. 2018).

Another example of synergies between values is hotspots of instrumental values that partially overlap with those places that were hotspots of the relational value sense of place. Sense of place is created through social and ecological interactions that foster a feeling of home and belonging. Such connections can contribute to nurture values of social cohesion and stewardship (Masterson et al. 2017; Martín-López 2021). The spatial overlap of grassland locations valued for instrumental values and sense of place indicates that feelings of belonging and feelings of home do not necessarily conflict with utilitarian management of the grassland but can also nurture each other. The fact that agricultural land, such as grasslands, is used economically might be important for this place to be kept intact and avoid abandonment or conversion to cropland. This result is also shown by the CCA, which illustrates that instrumental values and sense of place are related to provisioning ecosystem services.

4.4 The added value of plural valuation in space: recommendations for grassland management

Environmental values cannot fully explain the actions of people (Kaiser et al. 1999) but it is prominent that the values that people hold towards nature and ecosystem services do contribute to how nature is used and how future scenarios are envisioned (Pascual et al. 2017; Harmáčková et al. 2021). In this regard plural valuation can help to unravel values that are not yet integrated in management objectives and can foster recommendations for environmental management (Arias-Arévalo et al. 2017). De Vreese et al. (2019) also found that using social representations of nature that include relational values can result in more effective planning and management of ecosystem services and contribute to a better understanding among and between actor groups. In a recent study on riparian buffers in the northwestern USA Chapman (2019) concluded that several conservation programs conflicted with values of farmers. Fortunately integrating relational values of potential participants can help to better design the programs leading to both increased participation and sustaining the values needed to maintain such programs by reflecting values such as stewardship or care (Chapman 2019). Relational values like care also play a role in our sample concerning the management decisions of farmers. For instance there are dominant hotspots of care in the Ammer study region in areas of extensive management such as the alpine regions of the Ammer and Wetterstein mountains. One respondent explained – *'I am a farmer and an "alpine herdsman" in the Ammer mountains and would like to continue to manage it as I always have. The Ammer mountains are so beautiful due to the management, so we do not need a change (2,020,335)'*. This finding is in line with other studies claiming that the relational value of care can help to better understand the cultural dimensions behind stewardship actions (Jax et al. 2018; West et al. 2018). The Ammer mountains indeed are a valid example of extensively managed grasslands that are part of a cultural heritage of seasonal alpine farming a tradition that is heavily endangered although it provides various ecosystem services and high biodiversity (von Heßberg et al. 2021).

Regarding changes in the landscape, the maintenance of relational values can be threatened. If rapid and extreme landscape changes take place, this might erode human-nature connectedness and relational values (Riechers et al. 2021). Examples of landscape changes regarding grasslands are the abandonment of alpine pastures but also the intensification of grasslands and the conversion into croplands. These are also highly relevant in our study region, exemplified by a farmer in our sample who indicated that – *'[…] a certain balance between grassland and cropland should be maintained. In the areas with more cropland we have less grasslands – reason enough to give grassland a higher value. Grasslands have to establish themselves against cropland, also in times of conversion bans […] (2,018,314)'*.

Interestingly, not only relational values, but also instrumental values can be linked to an extensive management of grasslands. The respondent cited above also indicated that *'[…] a further important point is the usage of the area in relation to the amount of cattle you have. In dairy farm areas with a lot of cropland, I find grassland more valuable as a farmer, as better fodder can be taken from grassland if cutting intensity is kept low. From cropland, on the other hand I receive lower quality fodder which is mainly good to receive quantity (2,018,314)'*. This statement exemplifies that instrumental values linked to provisioning services can positively affect the management of extensively management grasslands. Extensive management practices provide ample ecosystem services such as carbon sequestration and recreation (Le Clec'h et al. 2019).

The results of this study imply that combining the qualitative study of relational values with

quantitative and spatial methods can reveal important connections between values, people's characteristics, and perceptions on the suitability of grasslands to supply ecosystem services. This underlines the call of previous research for more mixed methods approaches in valuation studies (Jacobs et al. 2016; Tadaki et al. 2017; Schulz and Martin-Ortega 2018). Integrating the spatial dimension in plural valuation is a crucial step as space represents the dimension of simultaneity where things, events, and people exist at the same time and deals with the question how we can live together (Massey 2014). Grasslands located at hotspots of instrumental values might be accepted by the public to be managed intensively as these are predominantly valued by citizens that also indicated that they perceive grasslands to be very suitable to supply provisioning services. On the contrary, conservation might be socially acceptable and prioritized in those locations where citizens perceived 'subjective' intrinsic values and relational values of care. Similar outcomes were found by De Vreese et al. (2016) who identified a clear link between nature conservation statuses and the social value of ecosystem services. The meaningfulness of certain geographical places to people can also be enhanced by peoples' engagement with nature illustrating the necessity to disentangle the values people place on distinct sites (Karimi et al. 2020). Nevertheless our spatial results also claim that even sites with high instrumental values are not purely valued for their utility as relational values are also present.

Due to its diversity, we addressed relational values in a more detailed categorization than intrinsic and instrumental values. Based on values that were articulated more than ten times, we only found one significant cluster of relational sub-types. The articulated values of security and resilience resonated in the cluster analysis with altruistic verbatims. This suggests that aspects of resilience that can bring security in the long run (Plieninger and Bieling 2013) are also related to altruism towards other people and other generations regarding the present values of grasslands.

4.5 Methodological limitations

In this study, we used a mixed-methods approach to investigate values of grasslands. Combining a qualitative assessment of values with spatial hotspot analysis proved to be very suitable to better understand the distribution of values associated with grasslands and their ecosystem services. Nevertheless, we acknowledge limitations in line with the data acquisition and analytical techniques.

The questionnaire titled 'Agriculture, climate change, and nature conservation' might have predominantly motivated citizens with interest in this topic to respond. This means that it is likely that citizens with an interest in conservation are overrepresented in the sample. Also, the sample characteristics revealed a bias towards higher educated citizens (Table B1). This could also be caused by the implementation of the survey as an online version that might not be accessible or attractive to some potential participants. These limitations need to be acknowledged, as a central point of plural valuation is recognizing and including marginalized stakeholders and less powerful people, for which other methods might be more suitable such as storytelling, photovoice or transdisciplinary approaches (Zafra-Calvo et al. 2020; Martín-López 2021). The results also need to be considered with care as the respondents are not distributed equally over the entire study area (Figure A3). This is specifically relevant because land use types located in the respondents' surroundings have a stronger influence on preferences than land-use types that are located further away (Hedblom et al. 2020). In a study on social representation of nature and landscape De Vreese et al. (2019) pointed out the risk of collectivization of results with a small sample which we also acknowledge for this study. Also, not every citizen might be equally familiar with the area, which could have led to erroneous mapping of valuable grasslands (Brown and Alessa 2005; Zhu et al. 2010). We acknowledge the limitation that the map was not zoomable. Hence the locations are only an estimate of the specific grasslands meant, which resulted in the inability of conducting further spatial statistical analyses with the dataset. Overall, we obtained a relatively low response rate (1.4%) compared to similar studies. For example, in Sherrouse et al. (2011) 33% of households returned a mail survey in Colorado, USA. Wagner et al. (2019) at least obtained a response rate of 7% in a study on stakeholders' perceptions on urban green spaces. A discussion with the postal agency revealed that direct mail circulars frequently even obtain lower response rates than ours as the mail can easily be considered to be bulk mail. The high number of postcal cards sent allowed us to still conduct meaningful analyses with the dataset.

We further acknowledge uncertainties that we encountered during the QCA with data from questionnaires without the possibility to follow up on the answers. Several respondents did only indicate short or imprecise statements about why they value specific grasslands that we could not allocate to a value category leading to less data points for the spatial analysis and a missing recognition of underlying values. In order to keep the subjectivity bias for assigning value types to verbatims as low as possible, decisions regarding value categorization were discussed by all authors.

The limitations outlined should be addressed in future research in order to fine-tune our understanding of values that predominate in grasslands and give precise location-specific policy and management recommendations. Nevertheless, our results combining qualitative methods with a spatial analysis provided interesting insights into the distribution of values in two study regions in Bavaria, Germany, that can be used to identify trade-offs and synergies between values in a spatial dimension and showed the possibilities to gain practical insights for prioritization of certain grassland management practices.

5 Conclusion

The goal of this study was to explore the spatial distribution of values associated with grasslands and their ecosystem services. By means of combining qualitative and quantitative data and analytical techniques, we conclude that *(i)* trade-offs between instrumental and intrinsic values that have been reported in recent studies can also be found spatially; *(ii)* relational values, such as care or sense of place, overlap in several locations with each other as well as with intrinsic and instrumental values, which means that relational values can act as a bridge between the two opposing values; *(iii)* sociodemographic variables and perceived suitability of grasslands to supply ecosystem services are clearly linked to the verbatims coded as instrumental, intrinsic, or relational values.

The results of this study on the values of grasslands underline the importance of plural valuation including relational values for sustainable land management. The methods employed can help to understand which people are more likely to benefit or lose from decisions about agricultural management, economic development, or biodiversity conservation and can provide important information for land use prioritization and management advice.

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Appendix A. Additional information on the study areas

Table A1. Distribution of the workforce in the main counties of the study area (in percent)

County (*Landkreis*)	Study area	Agricultural, forestry, fishery industries	Manufacturing industry	Service industry
Garmisch-Partenkirchen	Ammer	1.6%	14.2%	84.2%
Landsberg a. Lech	Ammer	2.6%	28.2%	69.2%
Weilheim-Schongau	Ammer	2.8%	36.4%	60.8%
Bayreuth (Town)	RWMain	0.3%	16.9%	82.9%
Bayreuth (County)	RWMain	3.8%	33.3%	63.0%
Kulmbach	RWMain	2.0%	36.6%	61.4%
Bavaria (State)		1.6%	27.3%	71.1%

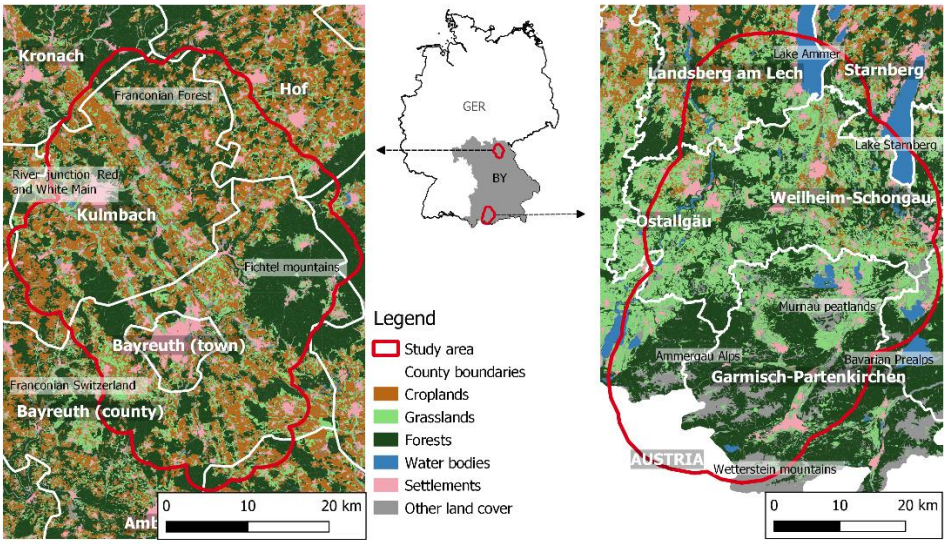


Figure A1. Regions of interest in the RWMain study area (left) and Ammer study area (right).

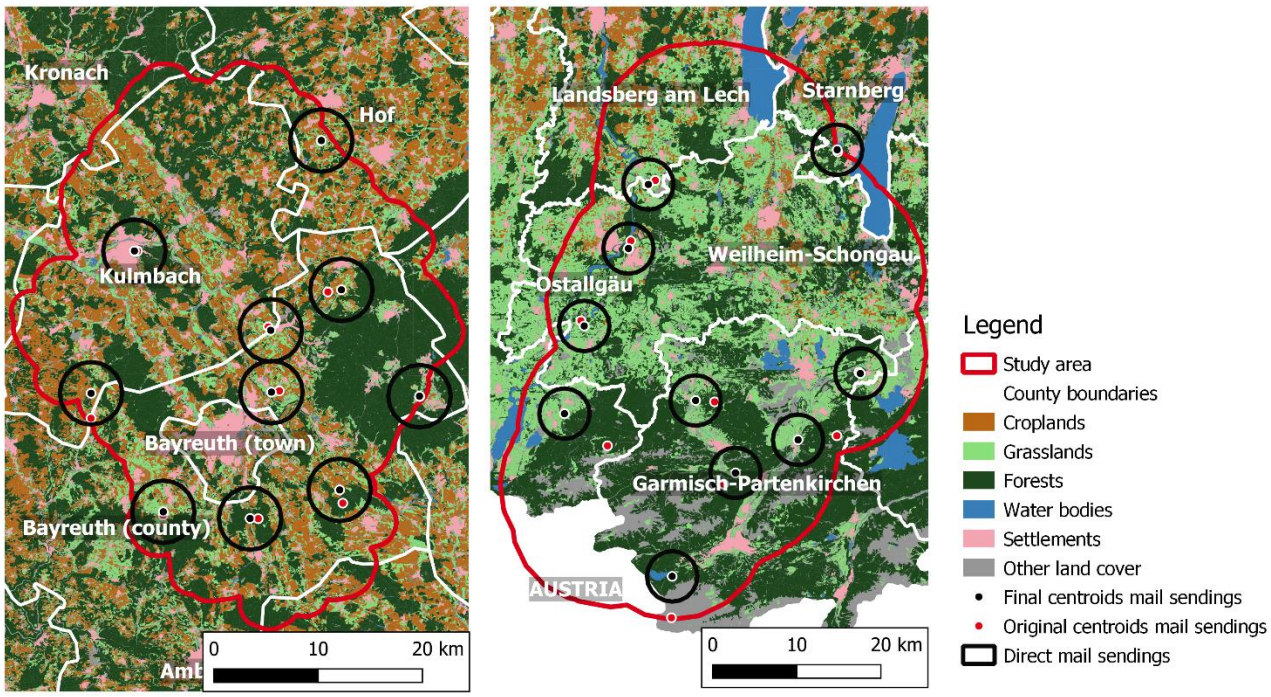


Figure A2. Centroids of the final direct mail sending circles (blue) and its original counterparts (red) that were adjusted when placed in areas of very low population.

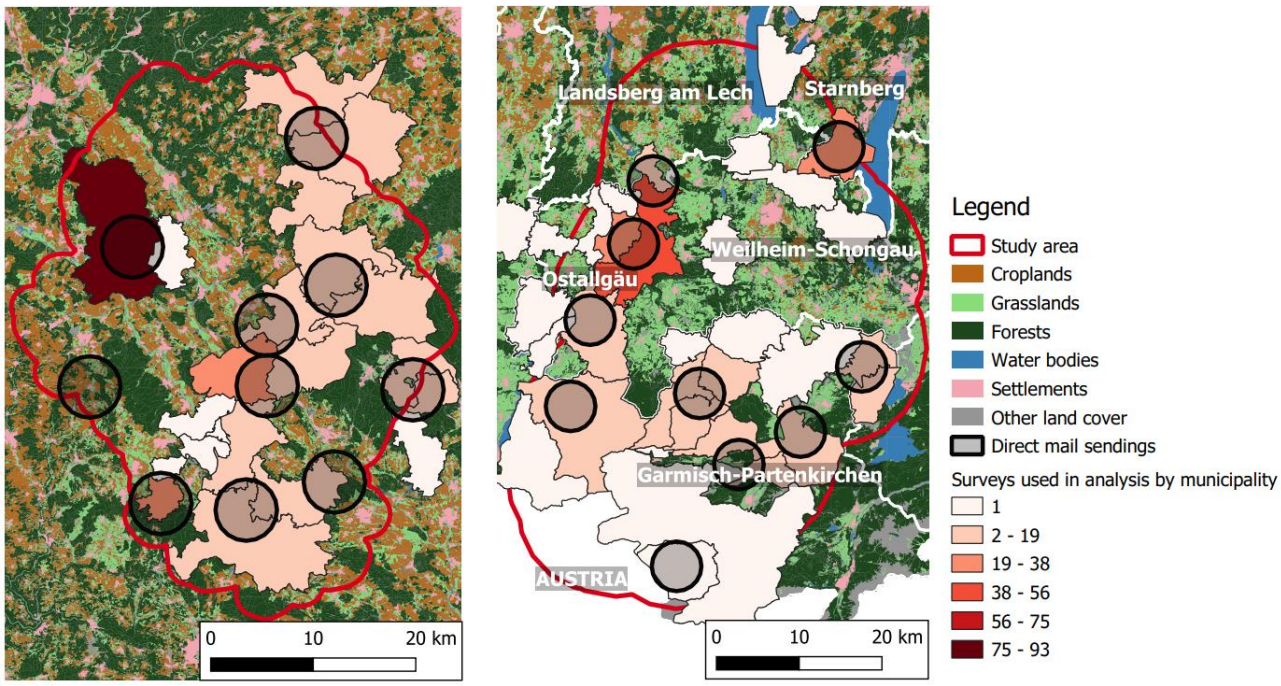


Figure A3. Surveys used in the analysis based on municipality

Appendix B. Sample characteristics

Table B1. Characteristics of the respondents who indicated points and a reason on the importance of grasslands (n = 515)

Characteristics	Respondents
Gender	
Male	60.6%
Female	36.3%
Diverse	0.2%
No response	2.9%
Age	
< 18	0.8%
18-25	5.8%
26-30	7.6%
31-35	5.0%
36-40	8.0%
41-45	7.0%
46-50	12.0%
51-55	16.1%
56-60	10.9%
61-65	9.3%
66-70	8.7%
>70	6.6%
No response	2.1%
Education	
No school diplona	0.4%
Lower secondary education	7.4%
Middle secondary education	25.6%
Higher secondary education	63.1%
No response	3.5%
Year of survey	
2018	49.7%
2020	50.3%
Study region	
Ammer	52.6%
RWMain	47.4%
Employed in activities related to nature	
yes	23.3%
no	76.7%

Private activities in nature	
Hiking, Running, Cycling	92.4%
Observing wild animals	36.1%
Collecting mushrooms, wild herbs, or berries	46.4%

Appendix C. Overview of the questionnaire

Relevant questions of the questionnaire. Translation in grey. Comments in red. For the full version of the questionnaire please contact the corresponding author.

Online-Umfrage 2018 "Klimawandel, Landwirtschaft und Naturschutz"
Online Survey 2018 „Climate change, Agriculture and Nature conservation“

Short introduction / project description

Ihre Teilnahme dauert ca. 12 min und ist absolut **freiwillig**. Die Antworten werden **anonymisiert** und lassen sich nicht auf Ihre Person zurückführen. Ihre persönlichen Angaben werden streng vertraulich behandelt und nicht an Dritte weitergegeben.
Your participation takes app. 15 min and is entirely **optional** and non-binding. The questions are anonymous and cannot be traced backed to you. We will also treat your personal answers strictly confidential and they will not be passed on to third parties.

Bitte füllen Sie den Fragebogen **vollständig und so genau wie möglich** aus. Die Qualität der Forschungsergebnisse hängt davon ab.
Please answer the survey as **complete and exact as possible**. The quality of our research results depends on this.

Es können auch gerne **mehrere Personen in Ihrem Haushalt** einen Fragebogen ausfüllen - einfach eine Umfrage abschliessen und eine neue öffnen. Wichtig ist aber, dass ein Fragebogen jeweils nur durch eine Person bearbeitet wird.
It is possible that **multiple people in your household** fill out this survey – simply close the survey and open a new one. It is important that each survey is only filled out by one single person

Wir freuen uns auf Ihre Meinung!
We are looking forward to hearing your opinion!

*) In den Landkreisen Bayreuth, Kulmbach und Hof sowie den Landkreisen Garmisch-Partenkirchen, Ostallgäu und Weilheim-Schongau wurde Ihr Haushalt zufällig ausgewählt.
*) We randomly selected households in the counties of Bayreuth, Kulmbach and Hof as well as Garmisch-Partenkirchen, Ostallgäu and Weilheim-Schongau to take part in this study.

Q2.1 **Zuerst einige allgemeine Fragen zu Natur und Landschaft**
First, some general questions to nature and landscape

Q2.2 Nutzen Sie privat Natur und Landschaft in Bayern?
Do you privately use nature and the landscape in Bavaria?
Are you taking part in activities related to nature?

- o nein no
- o weiss nicht don't know
- o ja yes

Q2.3 Wenn ja, für welche privaten Aktivitäten nutzen Sie Natur und Landschaft in Bayern? Bitte klicken Sie an.
If yes, please choose:

- ▢ Wandern, Joggen oder Radfahren Hiking, running or cycling
- ▢ Wildtiere beobachten watching wild animals
- ▢ Pilze, Wildkräuter oder Beeren sammeln collecting mushrooms, wild herbs or berries
- ▢ Motorrad- oder Autofahren Motorcycling or driving
- ▢ Angeln oder Jagen Fishing or hunting
- ▢ andere: something else_____

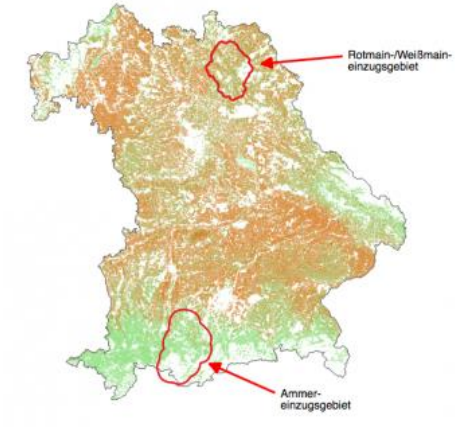
Q2.4 Haben Sie beruflich mit Natur und Landschaft in Bayern zu tun?
Are you professionally involved with activities related to nature and the landscape in Bavaria?

- o ja, hauptberuflich yes, full-time job
- o ja, nebenberuflich yes, part-time job
- o nein no
- o weiss nicht don't know

Q2.5 Wenn ja, um welche berufliche Tätigkeit handelt es sich?
If yes, please choose

- ▢ Landwirtschaft Agriculture
- ▢ Landwirtschaftsberater Agricultural advisor
- ▢ Forstwirtschaft Forestry
- ▢ Wasserwirtschaft Water resources management
- ▢ Umwelt/Geo/Biowissenschaft Environmental-/Geo-/Biosciences
- ▢ Naturschutzverband Nature conservation organization
- ▢ Fischerei Fishing
- ▢ Behörde (z.B. im Bereich Umwelt, Forst, Agrar, Wasser) Administration (e.g. in the sectors environment, forestry, agriculture, water)
- ▢ Imkerei Beekeeping
- ▢ Gartenbau Horticulture
- ▢ andere: something else _____

Q9.1 **Im Folgenden fragen wir speziell zu Grünland in den Wassereinzugsgebieten der Ammer und des Rotmains/Weißmains.** Auch hier geht es dabei stets um Ihre persönliche Einschätzung.
In the following, we ask spefically about grasslands in the study areas of the Ammer and Red and White Main. Here, the questions are also about your personal opintion.



Karte: Acker- und Grünlandflächen in Bayern (Quelle: Invekos 2014, StMELF) in Braun und Grün, sowie in Rot gekennzeichnet die beiden Fallstudiengebiete.
Figure: Crop. and grasslands in Bavaria (Source: Invekos 2014, StMELF) in brown and green; case study areas are marked in red.

Q10.1 Zu welchem Gebiet wollen Sie genauere Angaben machen?
For which area would you like to provide more detailed information?

○ Ammereinzugsgebiet (Landkreise Landsberg am Lech, Weilheim Schongau, Garmisch-Partenkirchen)
Study area of the Ammer catchment (Counties Landsberg am Lech, Weilheim Schongau, Garmisch-Partenkirchen)

○ Rotmain-/Weißmaineinzugsgebiet (Landkreise Kulmbach und Bayreuth)
Study area of the Red and White Main catchment (Counties Kulmbach and Bayreuth)

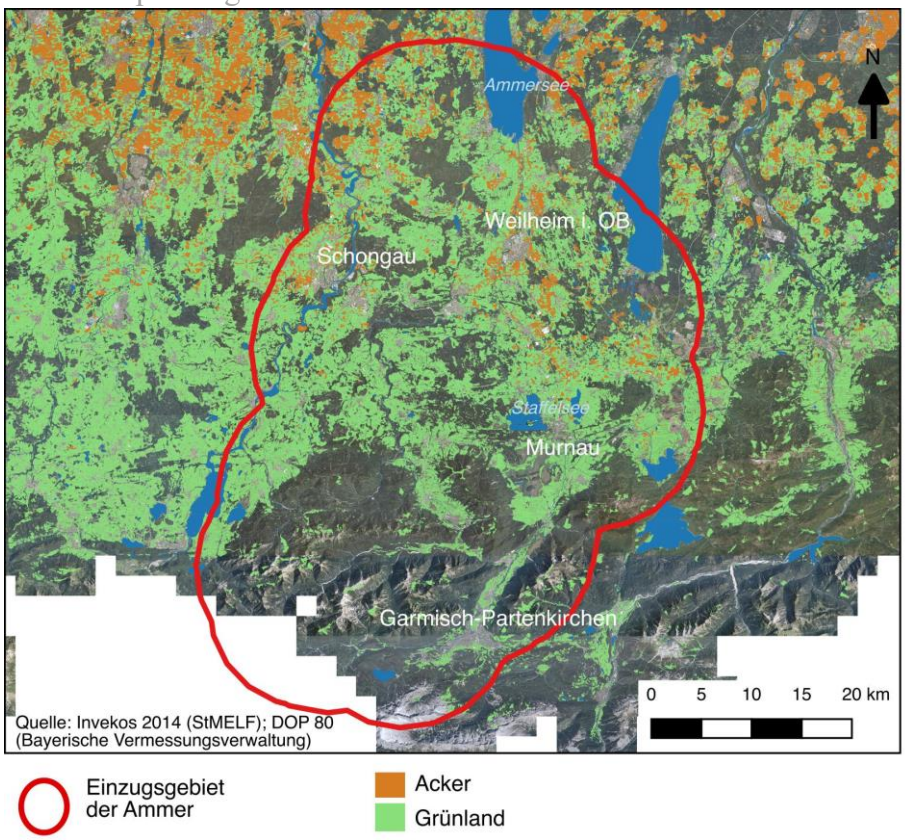
○ keine weiteren Angaben zu den Gebieten - ich möchte den Fragebogen abschliessen
no further details to the study areas – I would like to quit the survey

Q10.2 **Grünland** sind landwirtschaftlich genutzte Wiesen, Mähweiden, Weiden, Hutungen, Almen/Alpen und Streuwiesen und sind in der Karte **hellgrün** gefärbt.
Grasslands are agriculturally used meadows, pastures, hay meadows, alps, and straw meadows and are coloured in the map as **bright green**.

[If the respondent indicated the preference to give further details on the Ammer study area, the following questions were displayed]

Bitte markieren Sie in der Karte der Ammer aus Ihrer Sicht besonders wertvolles Grünland.
Please indicate on the map of the Ammer study area grassland that is especially valuable from your point of view.

Sie können max. 7 Punkte durch Klicken in der Karte markieren. Durch einen zweiten Klick können Sie einen Punkt wieder löschen.
You can indicate up to 7 points by clicking on the map. With a second click you can delete the point again.



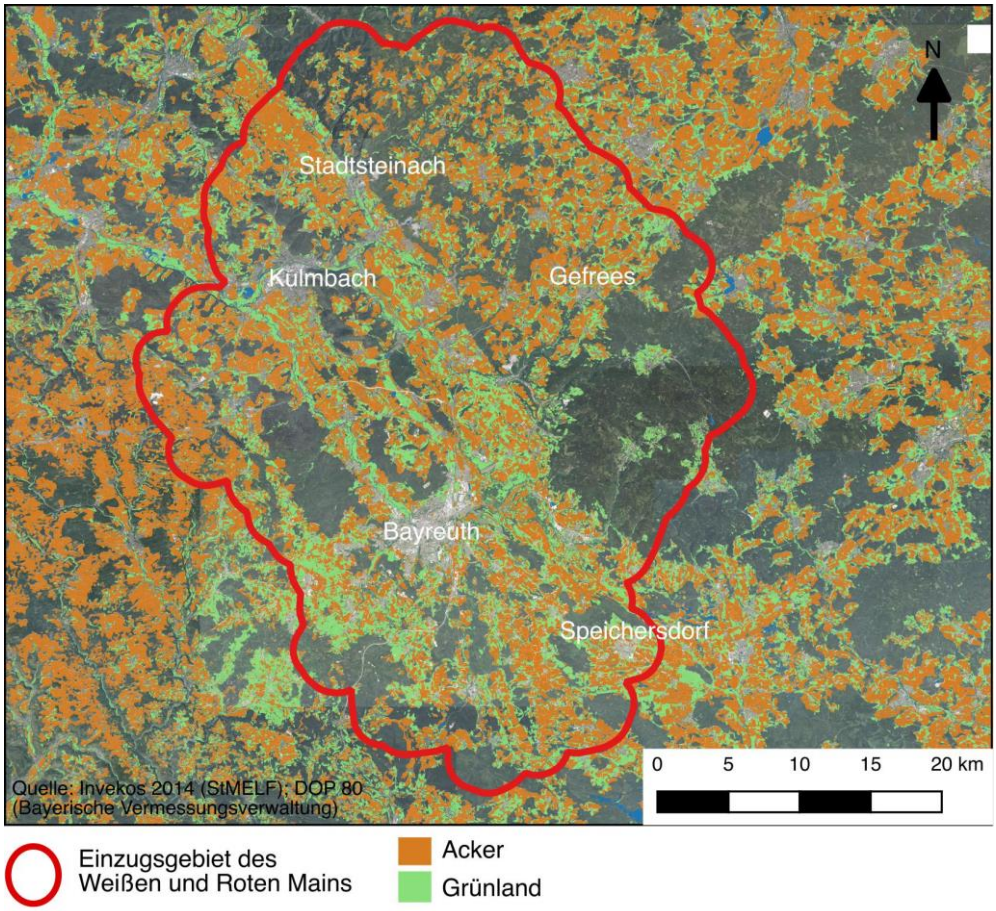
Q10.3 Warum haben Sie diese Grünland auf der Karte des Ammereinzugsgebietes ausgewählt? Bitte schreiben Sie eine kurze Erklärung.
Why did you choose these grasslands on the map of the Ammer catchment. Please give a short explanation.

_____

[If the respondent indicated the preference to give further details on the Red and White Main study area, the following questions were displayed]

Bitte markieren Sie in der Karte des Rot- und Weißmains aus Ihrer Sicht besonders wertvolles Grünland.
Please indicate on the map of the Ammer study area grassland that is especially valuable from your point of view.

Sie können max. 7 Punkte durch Klicken in der Karte markieren. Durch einen zweiten Klick können Sie einen Punkt wieder löschen.
You can indicate up to 7 points by clicking on the map. With a second click you can delete the point again.



Q10.5 Warum haben Sie dieses Grünland auf der Karte des Rotmain-Weißmaineinzugsgebietes ausgewählt? Bitte schreiben Sie eine kurze Erklärung.
Why did you choose these grasslands on the map of the Ammer catchment. Please give a short explanation.

_____

[The following questions were display to all participants; the choice of answers was displayed for all eleven ecosystem services]

Q9.6 Für wie geeignet halten Sie **Dauergrünland** (Wiesen und Weiden) für die
160 Erbringung der folgenden Leistungen im Ammereinzugsgebiet? [/Rotmain-/ Weißmaineinzugsgebiet]
How suitable do you perceive permanent grasslands (meadows and pastures) to provide the following ecosystem services in the Ammer catchment [/catchment of the Red and White Main]:

Sehr ungeeignet (- -) Very unsuitable	Ungeeignet (-) Unsuitable	Weder ungeeignet noch geeignet (- / +) Either/ or	Geeignet (+) Suitable	Sehr geeignet (+ +) Very suitable	Ist mir unbekannt (?) Unknown

Produktion von Tierfutter im Dauergrünland (z.B. Grassilage, Heu)
Production of animal fodder (e.g. grass silage, hay)

Tierproduktion im Freiland (z.B. Milchkühe und Ochsenmast auf Weiden)
Animal production on open land (e.g. dairy cows on pastures)

Produktion von Energiepflanzen im Dauergrünland (Grassilage für Biogasananlagen)
Production of energy by plants on permanent grassland (grass silage for biogas plants)

Erhalt der Bodenfruchtbarkeit (durch natürliche Bodenprozesse)
Retention of soil fertility (by natural soil processes)

Schutz der Grundwasserqualität (durch Stickstoffrückhalt in der Vegetation)
Protection of ground water quality (through nitrogen retention in the vegetation)

Regulation des globalen Klimas (durch Aufnahme von Klimagasen wie CO2 und Speicherung in Böden und Vegetation)
Regulation of the global climate (by uptake of climate gasses such as CO2 and storing in soils and vegetation)

Minderung der Wassererosion (durch Vegetationsdecke)
Reduction of water erosion (through vegetation)

Hochwasserschutz (durch Retentionsflächen in Auenbereichen)
Flood risk reduction (by retention in riparian areas)

Bestäubung von Kulturpflanzen (durch wildlebende Insekten)
Pollination of cultural plants (by wild insects)

Biologische Schädlingskontrolle (durch wildlebende Insekten und Vögel)
Biological pest control (by wild insects and birds)

Erholung in der freien Landschaft (durch Naturerleben und Landschaftästhetik)
Recreation in the open land (by experiencing nature and landscape aesthetics)

Q13.1 Welches Geschlecht haben Sie?
What is your gender?

- männlich male
- weiblich female
- divers diverse
- keine Angaben no answer

Q13.2 Welcher Alterskategorie gehören Sie an?
What age category do you belong to?

- Unter 18 below 18
- 18-25
- 26-30
- 31-35
- 36-40
- 41-45
- 46-50
- 51-55
- 56-60
- 61-65
- 66-70
- über 70 older than 70

Q13.3 Welchen höchste allgemeine Schulausbildung haben Sie?
What is your highest general education you attended?

- Haupt-(Volks-)schulabschluss Lower secondary education
- Abschluss der polytechnischen Oberschule Middle secondary education
- Realschul- oder gleichwertiger Abschluss Middle secondary education
- Fachhochschul- oder Hochschulreife Higher secondary education / University entrance qualification
- Ohne allgemeinen Schulabschluss No school diploma
- Keine Angabe No answer

Appendix D. Additional information

Table D1. Values of grasslands that were indicated by the respondents by study area and year..

		2018	2020	Total
Ammer	Instrumental	6	6	12
	Intrinsic	34	34	68
	Relational	70	52	122
RWMain	Instrumental	2	6	8
	Intrinsic	22	31	53
	Relational	46	67	113
Total	Instrumental	8	12	20
	Intrinsic	56	65	121
	Relational	116	119	235

Table D2. Statistical information (p-values) of the Mann-Whitney-U-Test analyzing differences in the distribution of value domains valued between the RWMain and Ammer study area (Region) and between the 2018 and the 2020 sample (Year).

Value domain	Region (p-value)	Year (p-value)
Instrumental	0.501	0.376
Intrinsic	0.368	0.390
Relational	0.759	0.886

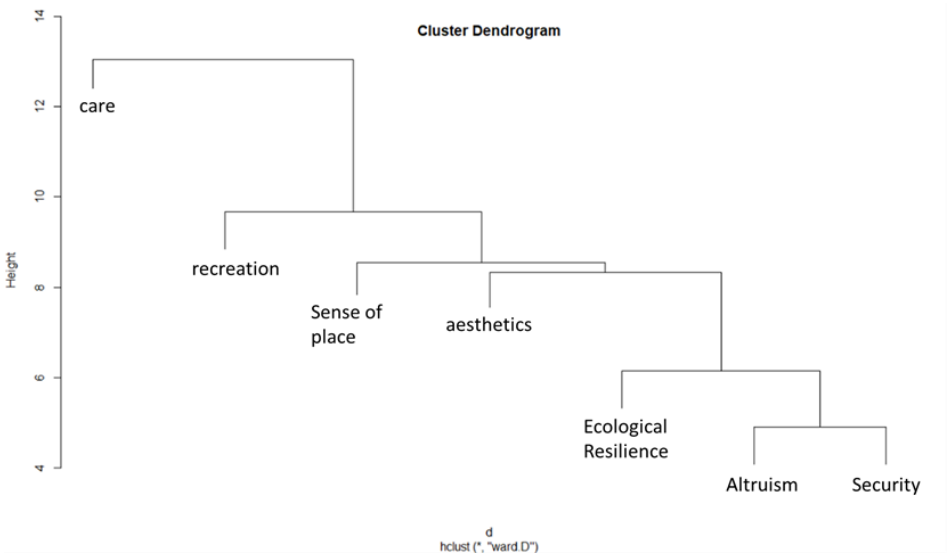


Figure D1. Results of Ward hierarchical clustering (1: Aesthetics, 2: Altruism, 3: Care; 4, Ecological resilience, 5: Recreation, 6: Security, 6: Sense of place)

Table D3. Statistical information (p-values) of the Mann-Whitney-U-Test analyzing differences in the distribution of relational values between the RWMain and Ammer study area (Region) and between the 2018 and the 2020 sample (Year).

Relational value sub-types	Region (p-value)	Year (p-value)
Aesthetics	0.247	0.125
Care	**0.081**	0.867
Recreation	**0.038**	0.294
Sense of place	0.401	0.645
Altruism,Security,EcoRes	0.148	0.470

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PAPER III

Recreation and its synergies and trade-offs with other ecosystem services of Alpine and Pre-Alpine grasslands (Paper 3)

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Status: Under Review (March 2023)

Abstract

Alpine and pre-Alpine grasslands provide numerous ecosystem services including provisioning services (e.g., fodder production), regulating services (e.g., soil erosion reduction), and cultural services (e.g., recreation). While intensively managed grasslands specifically target the production of fodder, more extensively used grasslands are known for being hotspots of biodiversity. However, there is a need to better understand the relationship among the supply of ecosystem services, specifically regarding cultural ecosystem services such as recreation. In this study, we investigtated the synergies and trade-offs of ecosystem services and analyzed underlying variables related to recreation. We investigated the supply of recreation (indicated by Photo-User-Days from geo-tagged photos on grasslands), fodder production (indicated by yield), as well as regulating and habitat ecosystem services (indicated by agri-environmental payments), and analyzed their relationship to management-related variables with a Redundancy Analysis. To better explain the recreational values of grasslands, we further analyzed how environmental and infrastructural features influence the occurrence of Photo-User-Days with a hurdle regression. Finally, we conducted spatial analyses to understand the distribution of Photo-User-Days in space. We found a weak, but significant negative relationship between Photo-User-Days and yield, which implies that people slightly prefer extensive grassland to intensive grassland for recreation. Our results also show that agri-environmental schemes targeted towards extensive grassland management can positively influence recreational value. Other factors, such as proximity to touristic features (e.g., castles), presence of infrastructural features (e.g., cable cars), and environmental characteristics (e.g., low share of croplands, distance to forests), also influenced the spatial distribution of photos on grasslands. The importance of these factors indicates the value of grasslands for recreation being a component of the cultural landscape. These results also suggest that cultural ecosystem services of grasslands can be considered to be co-produced by natural, social, and infrastructural components. The study further discusses limitations to the explanatory power of geo-tagged photo analysis to determine the wide range of cultural ecosystem services of grasslands. We conclude that grasslands play an important role for recreation in (pre-) Alpine landscapes, which can also be effectively supported through targeted agri-environmental payments.

Keywords: cultural ecosystem services, geo-tagged photos, grasslands, mountains, synergies and trade-offs

1 Introduction

Grasslands are widely distributed across the globe, covering roughly one third of the world's terrestrial land cover. They are important contributors to various ecosystem services, including provisioning services (e.g., fodder production), cultural services (e.g., recreation), regulating services (e.g., soil erosion reduction), and habitat for biodiversity (Bengtsson et al. 2019). Particularly, grasslands that are extensively managed are considered hotspots of biodiversity (Habel et al. 2013). Extensively managed grasslands are usually subject to less grazing pressure, fewer number of mowing events, and less fertilizer application. In Europe, particularly in Alpine areas, extensively used pastures have been facing rapid abandonment while intensively used grasslands have been managed even more intensively to supply high fodder production (Monteiro et al. 2011; Cocca et al. 2012; Schirpke et al. 2019).

To investigate the impact of such changes on ecosystem services supply, it is important to study multiple ecosystem services and their relationships. Specifically, there are contradictory findings concerning the relationships of cultural ecosystem services with other ecosystem services. For example, Le Clec'h et al. (2019), on the one hand, identified trade-offs between provisioning and all other ecosystem services in extensively managed pastures. On the other hand, intensively managed grasslands favour both outdoor recreation and fodder production. These findings on visitation rates (based on crowd-sourced photos) contradict general aesthetic preferences of people for grasslands with higher biodiversity. For example, in a study in Swiss agricultural landscapes, Junge et al. (2015) found higher aesthetic preferences on species-rich than on intensively managed grasslands.

Cultural ecosystem services include recreation and education, aesthetics, or sense of place. Such services contribute to income and are often non-substitutable to people (Howley et al. 2011, 2012, Junge et al. 2011, 2015; López-Santiago et al. 2014; Schirpke et al., 2016; Scolozzi et al., 2015; Bengtsson et al., 2020). However, they are relatively complex to quantify and have only been gaining increasing attention in recent years. The use of crowd-sourced photos from platforms such as Flickr has been successfully applied in assessing cultural ecosystem services (Figueroa-Alfaro and Tang 2017; Lee et al. 2022). The meta information obtained from crowd-sourced database, such as locations, dates, and user information of the photos, has been frequently used to calculate the visitation rate of certain places that can be assumed to approximate recreational ecosystem services (Wood et al. 2020; Ghermandi 2022). In other (semi-natural)

contexts, infrastructural and environmental factors were assessed to be important underlying factors influencing photo locations (e.g., Havinga et al., 2021; Lee et al., 2022). Different management regimes can be present in grasslands, namely pastures for grazing, meadows for grass harvest, and combinations of the two. Also, grasslands differ in terms of management intensities regarding number of cuts, fertilization regimes, or livestock density. Such management decisions influence the supply of ecosystem services and biodiversity and can be regulated by policy mechanisms such as agri-environmental schemes or protected areas (Beckmann et al. 2019; Schils et al. 2022).

Although landscape aesthetics and recreational activities have frequently been linked to open landscapes, the specific contributions of grasslands to recreation have rarely been analysed (Bengtsson et al. 2019). Furthermore, in a recent systematic review on grassland ecosystem services, Zhao et al. (2020) identified that, in order to generate knowledge for more sustainable grassland management, there is further research need in identifying underlying mechanisms of trade-offs and synergies between provisioning, regulating, and cultural services. This should specifically be conducted using multiple methods including different types of data acquisition. Thus, this study aims to deepen our knowledge on the relationships between ecosystem services in Alpine and Pre-Alpine grasslands and, specifically, unravel further underlying factors of recreation on grasslands.

To tackle the outlined gaps in research, we specifically aim to (1) quantify grassland ecosystem services, namely recreation (geo-tagged photos), fodder production (yield), and regulating/habitat services (using agri-environmental payments as a proxy) and assess their synergies and trade-offs, (2) analyse how additional infrastructural, environmental, and policy mechanisms are related to recreation; and finally (3) explore spatial patterns of recreation in the study area. We hypothesize that extensively managed grasslands are more frequently visited than intensively managed grasslands due to the high biodiversity in extensively managed meadows and pastures in the Alpine region (Junge et al. 2015; von Heßberg et al. 2021). Based on results in different context, we also assume that additional aspects, such as proximity to castles, cable cars, or hiking trails, strongly influence recreational activities on grasslands (Lieskovský et al. 2017; Wood et al. 2020).

2 Methods 800

2.1 Study area

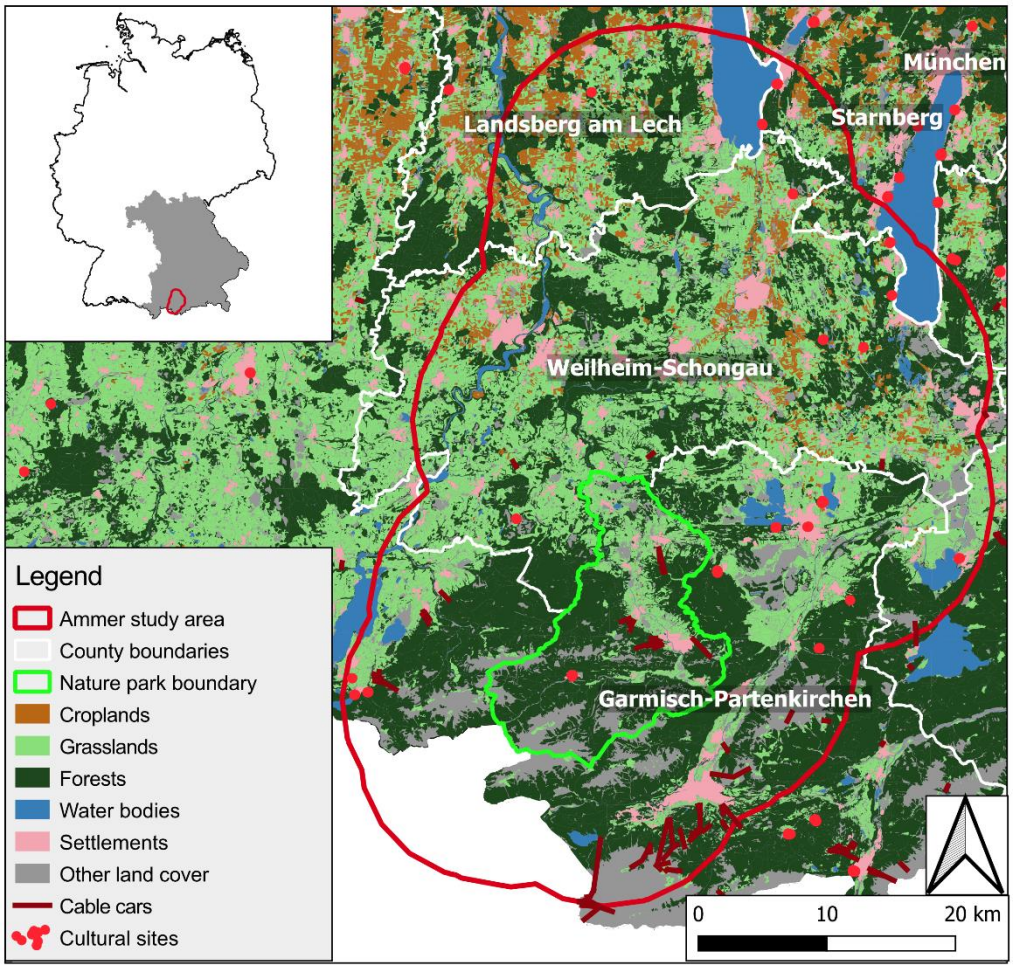

Fig. 1. Location and details of the study area in Bavaria, Germany.

The study area is located in Southern Bavaria (Germany) and is characterized by pre-Alpine foothills in the north (average of 881 m.a.s.l.) and Alpine mountains in the south including Germany's highest peak, "Zugspitze," with an altitude of 2,969 m.a.s.l (NASA, 2009). The mountainous part further includes sections of the Wetterstein mountains, Ammergau Alps, and Bavarian Prealps. The study area, based on the watershed of the river Ammer, consists of agricultural land (36%), forests (41%), lakes (5%), settlements (4%), and other land covers (14%), including mountainous rock and peat environments (LDBV, 2016). With 71% of its agricultural land use, the study area is strongly shaped by grasslands. Agricultural management practices differ throughout the study area, with proportionally more intensively used grasslands in the north and more extensive management in the south. The grassland share of the agricultural land use in the northern part is close to 50%. In contrast to this, the agricultural land of the southern part has a

grassland share of 99%, characterized by rather low management intensities. Grasslands in the southern part include traditional humpback meadows (Buckelwiesen), bedding meadows, and Alpine pastures. Structural change in the study area origins from a large number of small-scale farmers being taken over by larger agricultural farms or by expanding the agricultural businesses towards touristic use. Specifically, in the mountainous part, traditional land use practices such as transhumance and Alpine pastures are lost due to a lack of profitability and disproportional labour leading to an intensification of grassland management in the valleys. Agriculture takes a very high economic, ecological, and social importance in the study area. Furthermore, tourism plays a major role in the economic activities, specifically in the southern, mountainuous part of the study area (Ammergauer Alpen GmbH 2017).

2.2 Data preparation

We assessed the relationship between ecosystem services provided in grasslands based on established indicators (see Table 1). All the analyses that were carried out in this study are field-specific and based on the Integrated Administration and Control System (IACS) data provided by the Bavarian State Agricultural Institute, including information on field boundaries, land use categories, participation in agri-environmental schemes (AES), and a link to farm data including number and types of livestock.

Table 1. Overview of input variables for the statistical analyses. Ecosystem services and grassland-specific variables are used for the Redundancy Analysis. All variables are used for the hurdle regression model. ES = Ecosystem services; AES = Agri-environmental schemes.

	Variable	Indicator [unit]	Data (Year)
Ecosystem services indicators	Cultural ES (Recreation)	Photo-User-Days (PUD) [PUD/ha]	see *Photo-User-Days*
	Provisioning ES (Fodder production)	Yield [dt/ha]	See *Yield*
	Habitat/regulating ES	AES payments [€/ha]	Based on IACS (2019)[1]; see *Agri-environmental payments*
Grassland-specific variables	Agri-environmental schemes	AES extensive management [yes/no]	based on IACS (2019)[1]
		AES sustainable fertilization [yes/no]	
		AES biodiversity [low/medium/high]	
		AES organic farming [yes/no]	
	Dairy farming	Dairy cows on farm [yes/no]	IACS (2019)[1]
	Location in nature conservation areas	Location in Flora-Fauna-Habitat site [yes/no]	(LfU 2021)

		Location in landscape protection sites [yes/no]	
		Location in Nature Park Ammergau Alps [yes/no]	
	Grassland category	Meadow [yes/no]	IACS (2019)[1]
		Pasture [yes/no]	
		Meadow-Pasture [yes/no]	
		Seasonal summer pastures [yes/no]	
		Other grasslands [yes/no]	
Environmental and Infrastructural variables	Topography	Slope of grasslands [%]	ASTER GDEM (2009)
	Cable car	Distance to grassland [m]	ATKIS (2018)[2]
	Sports sites	Distance to grassland [m]	
	Cultural sites	Distance to grassland [m]	
	Cropland proportion	Proportion in 2km circle around grassland [%]	IACS (2019)[1]
	Forest distance	Distance to forest [m]	IACS (2019)[1] ATKIS (2018)[2] CORINE (2018)[3]
	Water distance	Distance to water bodies [m]	IACS (2019)[1] ATKIS (2018)[2] CORINE (2018)[3]
	Hiking trails	Presence 100m around grasslands [yes/no]	ATKIS (2018)[2]
	Cycling trails	Presence 100m around grasslands [yes/no]	
	Mountain bike trails	Presence 100m around grasslands [yes/no]	

[1] *IACS: Agricultural land use (Integrated Administration and Control System) from Bavarian State Ministry for Nutrition, Agriculture and Forests (StMELF).*

[2] *ATKIS: Land use and land cover (ATKIS) from Bavarian Agency for Digitisation, High-Speed Internet and Surveying.*

[3] *CORINE: Land Cover from European Union, Copernicus Land Monitoring Service 2018, European Environment Agency (EEA).*

Yield

Yield, the major agricultural output of meadows and pastures, is a frequently used proxy for provisioning ecosystem services of grasslands (e.g., Crouzat et al., 2015; Richter et al., 2021; Tasser et al., 2020). We calculated yield per ha for each grassland field based on a look-up table by the Bavarian Institute of Agriculture (LfL, 2018). This table indicates the yield based on grassland categories (e.g. meadows, mowing pastures, pastures), their respective management intensities (e.g. number of cuts, grazing intensity), and the level of yield (e.g. low, medium or high yields). Grassland types were taken from IACS data while management intensities were approximated by stocking rate per farm for pastures and the number of cutting events for meadows. The numbers of cuts were provided on parcel level and were derived from an optical satellite sensor-based approach which uses time series of reflectance data to automatically detect cutting events in

grasslands; The timing and frequency of cutting events derived from the satellite data (Sentinel-2) was aggregated from pixel-resolution (10m x 10m) to parcel level with a majority approach. The detected cuts were validated with an independent dataset and resulted in an accuracy (F1-Score) of 0.82 for the Ammer study area (see (Reinermann et al. 2022). We defined the yield level based on the grassland productivity index (Grünlandzahl) by the Bavarian soil appraisal. However, this indicator was not available for all grassland fields (1126 of 53573). In these cases, we used the field's maximum slope as an alternative indicator assuming that grasslands with steeper slopes have a lower yield potential.

Photo-User-Days

A popular indicator for assessing cultural ecosystem services, specifically recreation, are geo-tagged, crowd-sourced photos from online photo-sharing platforms such as Flickr (e.g. Figueroa-Alfaro and Tang, 2017; Le Clec'h et al., 2019; Schirpke et al., 2016). Flickr offers decades of publicly available information and thus serves as a valuable source of data for crowd-sourced photos (Wilkins et al. 2021). These photos include geo-locations of places where the photo was taken, the date when the photo was taken, and the user id. With metadata of photos from Flickr, Photo-User-Days (PUD) can be calculated that are frequently used as a proxy for recreation (Sonter et al. 2016; Levin et al. 2017; Oteros-Rozas et al. 2018). PUD are defined as the total number of days per year that a photographer took at least one photo within a cell (grasslands and associated buffer in our case) in a study area (Sharp et al. 2016). In our study area, we first downloaded all geo-tagged photos (n=8036) taken in 2019 in the study area using the R package photosearcher on February 07th, 2022 (Fox et al. 2020). We selected the photos taken on or within a 100m buffer around grasslands (n=1590) assuming that pictures taken within these boundaries relate to the surrounding grasslands (Schirpke et al. 2016; Le Clec'h et al. 2019). Secondly, we calculated PUD to avoid the bias of some users taking multiple photos on the specific location and the same day (n=1082 PUD). Thirdly, we divided the PUD by the actual size of the fields to determine a comparable unit, PUD per ha.

Agri-environmental payments

We calculated the total amount of agri-environmental payments received on each grassland field based on IACS data. Calculation of payments was a multi-step process due to complex allocations if multiple schemes are placed on one field or farm (see

Supplementary Information S1). We included payments based on the Bavarian KULAP (Cultural Landscape Program) and VNP (Nature Conserveration Program). These schemes are paid to compensate for the loss of yield on a field in favor of other ecosystem services (e.g. climate protection, soil- and water conservation, cultural landscape protection, and habitat for biodiversity). The total amount paid is thus an indicator for regulating and habitat ecosystem services

Independent variables

In addition, we were interested in how the specfic AES placed on grasslands relate to yield, recreation, and the total payments received. Hence, we also included the types of agri-environmental schemes present on specific fields as a grassland-management related, independent variable. We classified the types of agri-environmental schemes that are placed on specific fields into the following categories: (i) measures that promote extensive grassland management (e.g. max. 1.4 cattle/ha and renunciation of mineral fertilization); (ii) measures that facilitate sustainable fertilization techniques (e.g. low-emission distribution of organic fertilizers); (iii) measures classified according to their level of importance (high, medium, low) for promoting biodiversity (based on Horlitz et al., 2018); and (iv) fields belonging to all-organic farms (see Supplementary Information S1 for details on the AES classification). Although the data is based on the same dataset as the agri-environmental payments, the utilization of agri-environmntal schemes as independent variables provide additional information. They are also independent of the height of the subidy paid per scheme.

As additional variables classifying the grasslands, we included type of farming (dairy farms or non-dairy farms) as an indicator of grassland management intensity. This was decided with consultation of experts in the region, claiming that farms holding dairy cows need more energy-rich feed than non-dairy cow farms. Furthermore, we added location-specific characteristics, such as locations in nature protection sites, namely Flora-Fauna-Habitat sites (FFH), landscape protection sites (LSG), and the Nature Park Ammergau Alps.

We prepared additional environmental and infrastructural data that can influence the distribution of cultural ecosystem services in the study area (see Table 1). Variables were selected based on expert knowledge of the authors in the study area and on previous literature explaining the distribution of geo-tagged photos in the landscape (e.g., Lee et al., 2022; Oteros-Rozas et al., 2018).

2.3 *Statistical and spatial analyses*

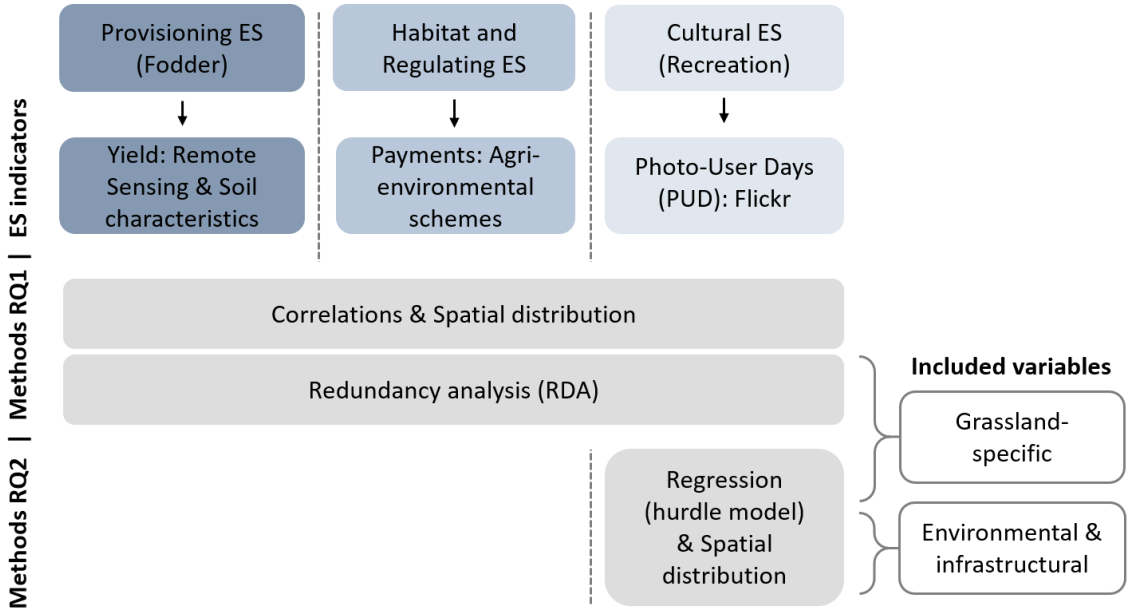

Figure 2. Analysis flow chart. Blue boxes show calculation of ecosystem service indicators (dependent variables); white boxes illustrate independent variables included in the analyses; grey boxes show statistical and spatial analyses conducted. ES = Ecosystem Services; PUD = Photo-User-Days; RQ = Research Question.

For the statistical and spatial analyses, we z-standardized all numerical variables. First, we conducted Spearman's Kendall to identify correlations between provisioning and cultural ecosystem services. Second, to determine the relationship between ecosystem service supply and grassland characteristics, we conducted a Redundancy Analysis (RDA). RDA is a frequently used tool in ecosystem services research (e.g. Bidegain et al., 2019; De Vreese et al., 2019; Martín-López et al., 2012) as it allows to relate multiple dependent variables with their potential predictors (Legendre et al. 2011). Variables that characterize grasslands and its management were used as independent variables (see Table 1). To identify significant variables for the RDA, we used forward selection building a model that maximizes the adjusted R^2 every step of adding a new variable. Dependent variables were indicators for ecosystem services provisioning, i.e. yield per ha (provisioning), PUD (cultural), and total agri-environmental payments (regulating and habitat ecosystem services). We conducted Monte-Carlo permutation testes (999 permutations) to determine the significance of the model and tested for collinearity. We used the R package *vegan* for the analyses (Oksanen et al. 2020).

Third, we conducted a regression analysis with further environmental and infrastructural factors, as we assumed that the distribution of PUD on grasslands can be influenced by additional variables. In addition to (i) management related variables, we

used (ii) land cover classes surrounding the grasslands, either by distance to the grassland (e.g., distance to water bodies) or by portion of the land cover within a 2 km radius (e.g., cropland ratio); (iii) presence of infrastructural elements such as hiking paths, cycling paths, or mountain bike trails within the 100 m buffer around grasslands; (iv) distance to touristic features such as cable cars, castles and UNESCO sites, and sport facilities. As the dependent variables were highly right-skewed with a high number of zeros, we applied a hurdle regression model. The hurdle regression accounts are more appropriate for the excess zeros than other frequently used models such as a Poisson regression (Feng 2021). Hurdle models consist of two parts: A binary logit model and a truncated Poisson or negative binomial model. We used the negative binomial model as it accounted well for overdispersion in our data. It also scored best concerning Akaike Information Criterion (AIC) values.

Fourth, we assessed the spatial distributions of PUD on grasslands. For kernel density plots, we only considered the presence or absence of PUD on grasslands. In this case, we used the centroids of grassland fields as an approximation of the point locations of photos taken. We used the function *bw.diggle (spatstat package)* to determine the optimal bandwidth of kernels. All grassland fields in the study area were defined as the window of observation. Finally, to determine clusters of PUD on grasslands with high numbers of pictures taken, we employed Getis-Ord Gi* statistics (Getis and Ord 1992).

3 Results

3.1 Relationship between ecosystem services and grassland management

Concerning the supply of cultural and provisioning ecosystem services on grasslands, we found a negative correlation between PUD per ha and yield per ha of grasslands in the study area. Kendall's rank (p-value < 0.05; tau = -0.012) correlation analyses revealed statistically significant, but very low correlations. We also visually analyzed the spatial distribution of provisioning and regulating/habitat grassland ecosystem services throughout the study area. As illustrated in Figure 3, the northern part of the study area shows on a 2-km-hexagon-average higher yield per hectare than the southern part of the study area. AES payments are higher in the southern part, especially high in a region dominated by peatlands. PUD are also predominantly located in the southern part of the study area (see Fig. 5 and Fig. SI 1).

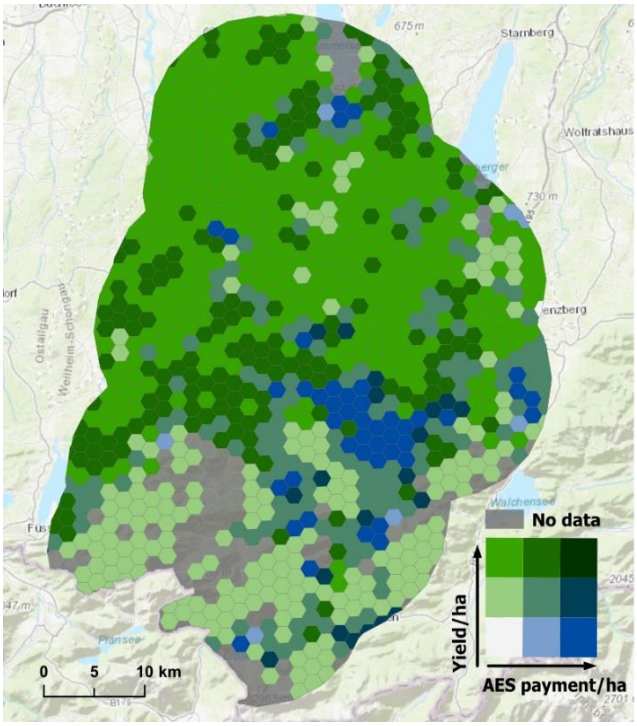

Fig. 3. Spatial distribution of provisioning (Yield / ha) and regulating/habitat (AES payment / ha) ecosystem service indicators. AES = Agri-environmental schemes

The Redundancy Analysis (RDA) indicated a statistically significant relationship between grassland management variables and indicators of ecosystem services. The analysis also supported the previously described significant, but low negative correlation between PUD and yield. The first axis of Figure 4 (33.3% of the variance) illustrates a dichotomy between yield provisioning and total agri-environmental payments per farm that indicates supply of regulating and habitat ecosystem services. The axis shows in the positive scores an association between yield provisioning on grasslands and farms that are keeping dairy cows, meadows, and farms that receive subsidies for climate-friendly fertilization techniques. On the negative scores, total agri-environmental payments per farm are associated with payments for extensive grassland management, payments for biodiversity-friendly farming, and grassland that are located in nature protection zones

(Flora Fauna Habitat areas). PUD per hectare show very low negative scores only and are located in the center of the axis. The second axis only explained 3.2% of the variance.

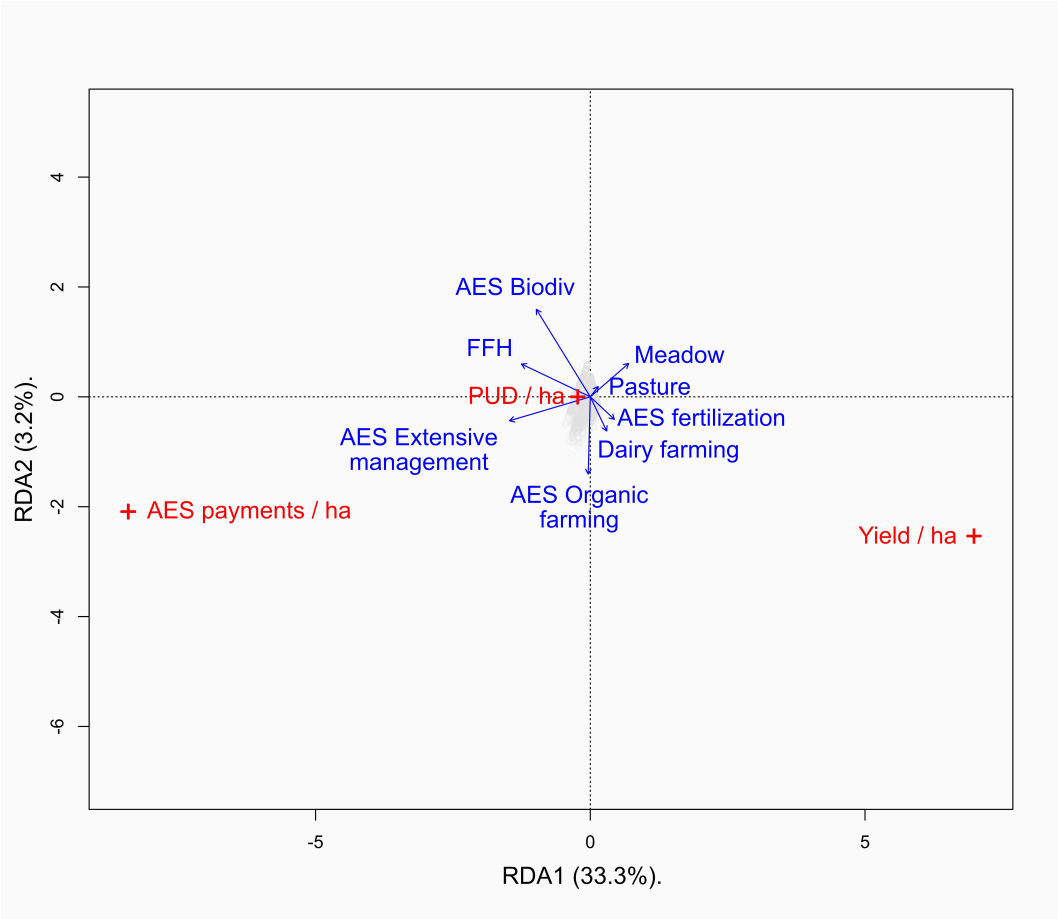

Figure 4. Redundancy Analysis (RDA) of grassland characteristics (blue) and indicators for ecosystem services (red). FFH = Flora-Fauna-Habitat sites; AES =Agri-Environmental Schemes; PUD = Photo-User-Days.

Table 2. Results of the first two axes of the Redundancy Analysis (RDA).

	RDA1	RDA2
Eigenvalue	1.00	0.10
Proportion explained	0.33	0.03
Cumulative proportion	0.33	0.37

3.2 Explaining variations in PUD on grasslands

The regression analysis revealed several significant associations between the number of PUD as well as environmental and infrastructural variables. The hurdle model showed two outputs: the count model assessing the influence of variables on the non-zero observations, so the number of photos taken on the grasslands (top) and the zero hurdle

model that predicts the non-zero observations, so the presence / absence of any photos taken on grasslands (bottom). Only two variables had a significant influence on the high numbers of photos on grasslands. The presence of grasslands in Nature Park Ammergau Alps positively influenced photos taken. The proportion of croplands in the surroundings of the picture taken negatively influenced high numbers of photos. Additional significant variables were found in the zero hurdle model: increased distance to cable cars, castles, and sports facilities had a negative influence on the presence of photos on grasslands. The presence of hiking trails within 100 m of grasslands and increased distance of water bodies positively influenced photos taken. We also found a significant influence of agricultural variables on the presence of photos. Yield had a significant negative influence on recreation, so did dairy cow farming (see Table 3).

Table 3. Regression coefficients for the hurdle model using Photo-User Days as the response variable. The hurdle model is separated into a truncated Negative Binomial model (top) and a binary logit model (bottom). Only statistically significant variables ($p < 0.05$) are displayed. AES = Agri-environmental schemes.

	Estimate	Std. Error	z value	Pr(>|z|)
Count model coefficients (truncated Negative Binomial model)				
(Intercept)	1.11	0.42	2.66	7.92E-03
Nature park	0.18	0.06	2.97	3.02E-03
Cropland ratio	-0.13	0.05	-2.37	1.77E-02
Zero hurdle model coefficients (binary logit model)				
(Intercept)	-1.73	0.48	-3.6	3.18E-04
Distance to cable cars	-0.14	0.03	-4.97	6.85E-07
Nature park	0.73	0.09	7.82	5.51E-15
Cropland ratio	-0.47	0.07	-6.43	1.25E-10
Distance to cultural sites	-0.21	0.04	-5.04	4.53E-07
Dairy cow farming	-0.26	0.08	-3.23	1.22E-03
Distance to peatlands	0.08	0.02	4.65	3.35E-06
AES extensive management	0.20	0.08	2.60	9.26E-03
Hiking trails present	0.23	0.08	2.94	3.34E-03
Yield per ha	-0.16	0.04	-4.12	3.87E-05
Distance to water bodies	0.07	0.03	2.47	1.34E-02
Distance to sports sites	-0.06	0.03	-2.52	1.17E-02

3.3 Spatial distribution of grasslands with PUDs

The Kernel density plot (Figure 5) illustrates the locations of clusters of grasslands with PUD present. The majority of these are located in the southern part of the study area, specifically around the town of Garmisch-Partenkirchen and in the Nature Park

Ammergau Alps. Getis-Ord Gi* Hotspots, illustrating locations with very high numbers of PUD on grasslands are located in the proximity of touristically attractive sites, such as "Neuschwanstein castle", UNESCO Pilgrimage church "Wieskirche", or the town of Garmisch-Partenkirchen close to mount "Zugspitze".

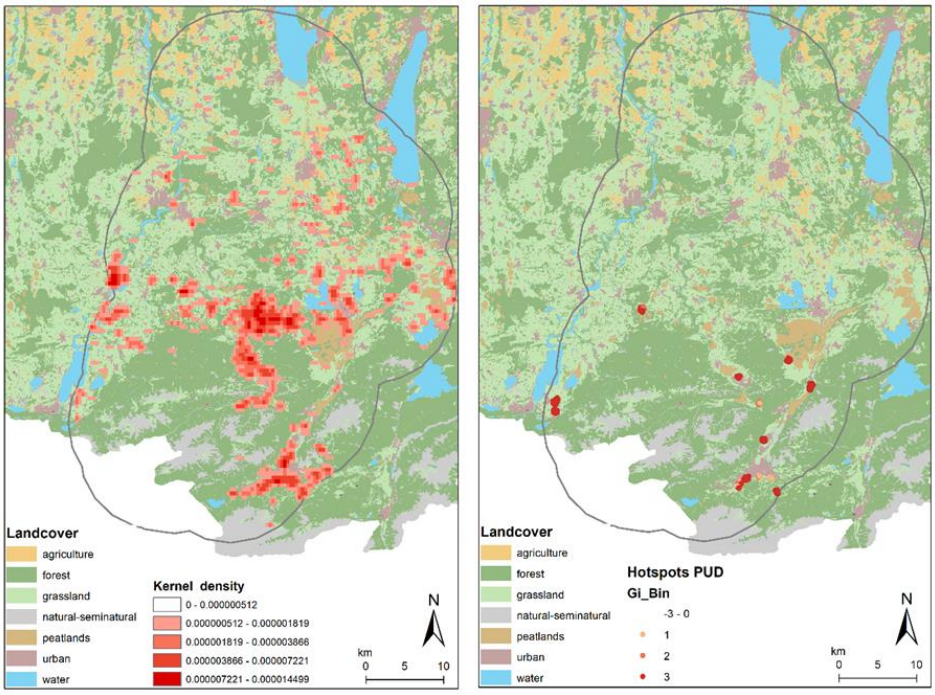

Figure 5. Spatial distribution of grasslands with at least one PUD (left) based on Kernel density and grasslands with high numbers of PUD of grasslands (right) based on Getis-Ord Gi hotspot analysis.*

4 Discussion

In this study we found that people slightly prefer visiting extensive grassland over intensive grassland, but infrastructural and environmental variables also play a fundamental role in explaining visitation rates. In the following section, we discuss the value of grasslands to provide recreational opportunities being part of the cultural landscape and advocate that cultural ecosystem services of grasslands are co-produced by influencing factors perceived by people. Governance approaches such as agri-environmental schemes that are targeted towards extensive grassland management and protected areas can positively influence recreation on grasslands. We lastly discuss limitations to the explanatory power of the study.

4.1 Synergies and trade-offs of ecosystem services in (pre-)Alpine grasslands

In the first part of the analysis, we aimed to identify relationships between ecosystem services in Alpine and pre-Alpine grasslands and associated management characteristics. The RDA revealed a negative relationship between grasslands that supply high yield and grasslands that receive high agri-environmental payments. These results indicate trade-offs between provisioning services on the one hand and regulating and habitat ecosystem services on the other hand. This is in line with findings of other studies on ecosystem services of grasslands. Simons and Weisser (2017), for instance, showed that agricultural intensification without biodiversity loss is possible in German grassland landscapes, but maximization of biodiversity conservation and fodder production is not feasible. In mountain grasslands, Schirpke et al. (2017) and Wu et al. (2017) found that trade-offs in grassland ecosystem services are influenced by management intensity with synergies and trade-offs between provisioning and other ecosystem services. In our study, grasslands classified as meadows and those grasslands that belong to farms holding dairy cows are an indicator of intensive management relating to fodder production in contrary to higher agri-environmental payments for regulating and habitat ecosystem services (see Fig. 4). In higher elevations of our study's Alpine environment, pastures are the primary agricultural land use and are increasingly abandoned due to high labor and low productivity, while in the valley bottoms meadows are continuously intensified (Monteiro et al. 2011; Cocca et al. 2012). The positive scores of dairy cow farming on the RDA can be explained by the high yield requirements in dairy systems as nutrient-rich fodder is required to increase milk outputs. In the study area, fodder is likely to be mainly grass-

based due to comparatively low milk yields. The milk yield various in the study area from less than 6000 kg/cow and year in the southern part to more than 7000 kg/cow and year in the western and northern part (LfL, 2019).

Regarding the relationship of provisioning and cultural ecosystem services, we found a weak, but negative correlation between PUD and yield of (pre-)Alpine grasslands with Spearman's tau. Le Clec'h et al. (2019) found trade-offs between yield and recreation in extensively used grasslands only, but not in intensively managed ones. In a recent study on effects of land use changes on aesthetics, Schirpke et al. (2021) found that grasslands had a positive effect on aesthetic value, even if intensively managed. Interestingly, in our study's regression analysis (see Table 3), the negative correlation between fodder production and recreation was only observed in the binary model. This also relates to the only weak negative relationship of numbers of PUD and yield in the RDA and correlation analyses. Hence, our results suggest that trade-offs between recreation and yield are mainly prominent at grasslands that are not visited and other factors strongly influence the number of photos taken.

4.2 Explaining recreation on pre-Alpine and Alpine grasslands

Our results revealed that besides fodder production, environmental and infrastructural variables influence recreation on grasslands. The influencing variables differ depending on the analysis, namely whether we analyze the total numbers of PUD per grassland or the presence/absence of photos taken on a grassland.

To explain the numbers of PUD per grasslands only two variables were significant, namely the presence of croplands in the surrounding area and location of the grasslands in the Nature Park Ammergau Alps. It is more likely that high numbers of photos are taken on grasslands that are located in an area of higher grassland share than in areas with a large amount of cropland. This result relates to studies that found a preference of people to visit regions that are dominated by grasslands rather than by cropland (e.g., Junge et al., 2015; Schirpke et al., 2021b, 2016) illustrating the importance of grasslands for recreation. The presence of grasslands in the study area is also heavily influenced by topography, with more grasslands in the more mountainous part of the study area. Protected areas have also been shown to be important for recreational activities. The Ammergau Alps Nature Park, in particular, still hosts a variety of extensively used grasslands such as summer pastures (*Almen*) that can be considered to be hotspots of biodiversity and are perceived as important for recreation to visitors (Ammergauer Alpen, 2017; von Heßberg et al., 2021). High biodiversity in agricultural landscapes can

positively effect visitation rates and provide higher attractivity of grassland (Junge et al. 2015). Besides supporting the result of previously conducted studies that explain recreation in different contexts, it is notable that both influential variables in - location in areas of high grassland share or in the Nature Park Ammergau Alps - are related to the southern part of the study area (see Fig. S1 in Supplementary Information S1). The southern part, mainly covering an Alpine environment, overall contains grasslands that are managed more extensively than the northern part, including straw meadows and summer pastures. The overall higher tourism occurrence in the southern part due to famous environmental (e.g., Mount Zugspitze) and cultural sites (e.g., Castle Neuschwanstein, UNESCO pilgrimage church Wieskirche) is also likely to contribute to that pattern. In a survey-based study, Schmitt et al. (2021) found that farmers located in this part of the study area are also more environmentally aware and perceive recreation as more important in their grassland management than farmers in the northern, pre-Alpine part of the study area.

We further identified several environmental and infrastructural variables that significantly correlate with the binary presence of photos on grasslands. Similarly to studies in other contexts (Oteros-Rozas et al. 2018; Schirpke et al. 2021; Lee et al. 2022), we illustrate the importance of infrastructural and environmental factors also to explain visitation rates of pre-Alpine and Alpine grasslands. Besides some natural and improved grasslands, a large amount of grasslands in the area are semi-natural and have been managed by humans for centuries. Thus, the results link to our initial hypotheses that it must be assumed that many photos are not only taken due to the aesthetic appreciation of the biodiverse grasslands itself, but as part of the cultural landscape also including historical and cultural sites. Aesthetics have been proven to be positively influenced by cultural, human-made components with long history and rich culture, such as castles or churches (Lieskovský et al. 2017). Cultural attractions also have been identified to have higher visitation rates than natural landscape features (Wood et al. 2020). The high importance of infrastructural and environmental variables for the distribution of PUD hints to co-production of ecosystem services. Besides the importance of biodiversity, most ecosystem services are not exclusively produced by natural processes, but actually co-produced by a mixture of natural, social, financial, and technological factors (Palomo et al. 2016). Specifically, cultural ecosystem services and its benefits can often be considered to be co-produced as they frequently origin from a combination of biophysical aspects, and factors such as management practices or accessibility factors (Chan et al.

2012; Daniel et al. 2012). Raymond et al. (2018) illustrated that cultural ecosystem services can be thought to be a result of the relationships of environmental and cultural factors. We show that recreation in grasslands depends on the contribution of natural components such as high biodiversity leading to perceived beauty, varying with management intensity, in combination with other infrastructural and environmental factors such as proximity to touristic features (e.g., castles, UNESCO sites), presence of infrastructural features (e.g., cable cars, hiking trails), and environmental characteristics (e.g., low share of croplands,).

4.3 Management and policy implications

We analyzed the relationships between ecosystem services of grasslands and identified further variables driving PUD, aiming to better understand the influence of management and policy decisions on the provisioning of recreational opportunities.

Tourism and recreational activities are sometimes perceived to be a negative contribution to nature conservation and ecosystem services due to disturbances associated with visitors. On the other side, recreation and tourism represent a major opportunity to support protection of ecosystems by fostering relationships among people and between people and nature (Gottwald et al. 2022). For grasslands, specifically, extensively managed grasslands are very important contributors for meaningful relationships of people and nature, such as sense of place or care and stewardship for nature (Schmitt et al. 2022).

Our results indicate that recreation on grasslands can be fostered by extensive management practices. Specifically, agri-environmental schemes targeted towards extensive grassland management were positively correlated with photos taken. Other programs, such as all-organic management and fertilization-targeting payments, did not have a major effect. One explanation for this might be the larger purchases needed for some of these programs such as new machinery, that are often made by larger farms only and less by small, extensively managed part-time farms (Pers. Comm., 2021). Conversion bans of grasslands that are in place in Bavaria, Germany, preventing land use changes from permanent grasslands to croplands, are also likely to be beneficial for recreation in the area as a higher grassland share contributed to the presence of photos taken. Furthermore, our results suggest that nature conservation areas that allow extensive management, such as Nature Parks or FFH areas, can contribute to recreation. Notably, as our study did only find marginal trade-offs between provisioning and cultural services, but prominent trade-offs between provisioning and regulating/habitat services, our results

are in line with findings of other studies illustrating that ecosystem services bundles should be managed simultaneously, even when specific targets are set (Crouzat et al. 2015).

Finally, quantification of recreation can provide useful insights for visitor planning and management (Schirpke et al. 2014, 2020). In this regard, our results support claim that touristic infrastructure such as hiking trails or cable cars can help to regulate visitor destinations. These variables showed a positive influence on photos taken on grasslands.

4.4 Limitations and future research needs

We acknowledge several limitations regarding the methodology used in this study. Although we employed well established indicators for ecosystem services, the resulting outcomes need to be interpreted with caution. Specifically, the approximation of regulating and habitat ecosystem services based on agri-environmental payments entails high uncertainties. Unfortunately, it is beyond the scope of this study to investigate the representativity of agri-environmental payments as an indicator for regulating and habitat ecosystem services. Nevertheless, when descriptively comparing agri-environmental payments targeting regulating and habitat ecosystem services in grasslands with the supply of regulating ecosystem services and biodiversity abundance modelled for Bavaria, Germany, there is a clear overlap. In the areas of high agri-environmental payments (sothern mountainous region), there is also a specifically high supply of carbon sequestration and erosion regulation. Addutionally in the area of the Murnau peatlands, there is also a high diversity of vascular plants, compared to the northern region characterized by grasslands of higher management intensity (see Fig. SI2).

Furthermore, some assumptions regarding the allocation of monetary units from agri-environmental schemes to grasslands (see SI), using slope as an indicator for productivity when grassland indices were not available, and specific data sources themselves, such as remotely sensed cutting intensities (Reinermann et al. 2022) or IACS data, entail uncertainties.

The use of crowd-sourced photos is an established indicator for cultural ecosystem services such as recreation, but entails several limitations (Wood et al. 2020). Flickr is one of the most predominantly used platforms for such data generation with very good result. For instance, Levin et al. (2017) found that Flickr explained more than 70% of variability in visitor numbers. However, some biases need to be acknowledged. For instance, crowd-source photos only cover certain recreational activities and are less representative of non-use values that are often associated with cultural ecosystem services

(Levin et al. 2017). Also, social media is tending to be used by the younger, wealthier, and more educated generation, creating a bias in the representativeness of the study to the population (Perrin and Anderson, 2019.; Wilkins et al., 2021). Flickr is decreasingly used by the public and replaced by platforms such as Instagram. Using multiple platforms could reduce biases in future studies (Wood et al. 2020; Wilkins et al. 2021). We also acknowledge that there could be differences in the seasonal patterns of photos (Schirpke et al. 2018), which limits this studies' findings specifically in the winter months as grasslands might not be easily observable when snow-covered. Also, more profound analyses with the data, such as content analyses of the pictures and tags with artificial intelligence or by qualitative analyses could limit the assumptions mentioned. These could also unravel specific ecosystem services and peoples' values targeted with each photo (e.g., Lee et al., 2022). Coupling the data with additional kinds of data such as social surveys could increase its accuracy and generalizability (Lenormand et al. 2018; Wilkins et al. 2021). This would also allow to investigate participants' worldviews, knowledge and values, which influence the perception of and decisions on ecosystem services (Peter et al. 2022). Investigating specific values of visitors, namely relational, instrumental, or intrinsic, would be especially interesting to understand the relationships with grasslands. Cultural ecosystem services are closely related to relational values, but much more in-depth understanding of the relationships can be gained from relational values These aspects were outside of the scope of this study, but could be of interest in future work.

We further acknowledge the presence of some of the major Bavarian tourist destinations in our study area that disproportionally attract visitors worldwide. Castle Neuschwanstein, the UNESCO cultural site Wieskirche church, and mount Zugspitze, attract millions of visitors yearly (LfStat 2021) and are surrounded by grasslands. Hence, grasslands with view onto these sites limit the generalizability of some results towards a wider or different region.

5 Conclusion

Based on the results of this study, we conclude the important role of grasslands for cultural ecosystem services. Extensively managed grasslands showed a slightly higher potential for recreation than intensively managed grasslands. Besides management intensity, the presence of photos on grasslands is highly associated with touristic infrastructure (e.g., cable cars, cultural sites, hiking trails) and environmental variables (e.g., distance to peatlands). Both intensively and extensively managed grasslands therefore seem to play an important role for co-producing recreation. The results imply that recreation on grasslands can be fostered by policy instruments such as targeted agri-environmental schemes and protected areas. For further studies, we suggest coupling the quantitative analysis of cultural grassland ecosystem services with qualitative data such as social media content or qualitative surveys.

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7 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Information

1. Fodder production: Remote sensing of cutting intensities

The timing and frequency of cutting events derived from the satellite data (Sentinel-2) was aggregated from pixel-resolution (10m x 10m) to parcel level with a majority approach. The detected cuts were validated with an independent dataset and resulted in an accuracy (F1-Score) of 0.64 for entire Germany (Reinermann et al. 2022) and 0.82 for the Ammer catchment area study region.

2. Calculation of total payments for Agri-Environmental Schemes per field

Our calculation of payments for Agri-Environmental-Schemes (AES), used as an indicator for payments for non-provisioning ecosystem services, was based on data from the Integrated Administration and Control System (IACS) for the year 2019. The ICAS dataset includes the spatial location of fields, the use of the field (crop), and the type of AES (101 different measures in 2019, including some that are only offered as an extension to a basic measure). Two different AES programs exist in Bavaria, the cultural landscape program (KULAP) and the nature conservation program (VNP). To calculate an estimate of payments per field, we used additional information published annually by the Bavarian Ministry of Food, Agriculture and Forestry ("*Merkblatt AUM 2019-2023*")[1]. In particular, the remuneration height for adopting a certain AES on the fields and what types of AES can be combined on one field. The combination of several measures (in 2019 up to 11 AES on one field), complicates the calculation of the total sum. Regarding the payment, different cases of combination types are possible:

a) "additive" type = the sum of all individual AES (original remuneration height) is paid
b) "higher" type = only the highest original AES remuneration height is paid
c) "top-up" type = a (smaller) top-up payment for an additional AES is granted

The methodological approach is not yet published elsewhere. In the following, we illustrate the steps undertaken in detail.

<u>Step 1: Identifying clearly assignable cases</u>

For the majority of fields with AES (94.3 %), we could assign the payment height with a high certainty. Those were:

a) Fields with only one single AES (66.7 %)
b) Fields with two "additive" measures (KULAP/VNP) or exclusively VNP measures, being all "additive" (23.2 %)
c) Fields with the combination type "higher" of two AES (3.4 %)
d) Fields with the KULAP measures "organic farming" in combination with certain "additive" VNP measures (0.8 %)
e) Fields with the combination type "top-up" of two AES (0.2 %)

<u>Step 2: Assigning the most plausible payment height to ambiguous cases</u>

The following procedure was taken for the remaining "complicated" cases of three or more AES on one field (5.7 % of fields with AES), with no combination type assigned after step 1. Certain AES require that farms participate fully (e.g., subsidies for organic

[1] https://www.stmelf.bayern.de/kulap

farming are only paid if the entire farm is certified organic) or with an entire branch of operation (e.g., all areas that are used to cultivate forage). These requirements for participation in measures are specifically marked ("*betriebsbezogen*" / "*betriebszweigbezogen*"). We assumed that those AES were sometimes added to all fields of a farm (or branch of operation of a farm) in the database without considering if the resulting combination of AES is possible. Therefore, we differentiated three cases for KULAP measures:

a) Only AES applicable to the entire farm / a branch of operation were present on a field => assignment of type "higher" (2.0 %)
b) Apart from the AES applicable to the entire farm / a branch of operation, only combinations of measures with the type "additive" remained => we added up all original remuneration heights for those ones (1.3 %)
c) Apart from the AES applicable to the entire farm / a branch of operation, only combinations of measures with the type "higher" remained => highest sum was chosen (0.4 %)

No undefined combination types of KULAP remained after this procedure.

For the remaining ambiguous combinations of KULAP with VNP measures (2.0 %), we assumed that after the removal of AES applicable to the entire farm / a branch of operation, the remaining AES (in most cases only "additive" VNP measures) received the full sum of all individual measures ("additive" combinations).

Step 3: Accounting for alteration of payments

Under certain circumstances, there is no payment for a certain measure, or the payment height is reduced or increased. This is true for the following cases (all of these were corrected accordingly):

a) The AES measure is not compatible with a certain field use
b) For a specific area setting, payments will not be made (because of existing legal requirements that do not allow for the payment of subsidies). Those areas are marked with four different codes in the dataset (e.g., no liquid manure allowed)
c) A reduced livestock density (B20, B21) receives only a reduced payment for areas classified as alpine pastures (use code 455)
d) Organic farming (B10) receives higher payment rates for permanent crops and for vegetable production.

Step 4: Making assumptions about payment heights

As some AES do not have a fixed remuneration per area but are based on other factors, we had to make certain assumptions in a few cases. Those were:

a) For the measures subsidizing low-emission fertilizer application (B25 / B26), payments are based on the volume of liquid manure applied. As the quantities were unknown, we calculated the payment based on the Bavarian average per hectare (personal communication with the Bavarian Ministry of Food, Agriculture and Forestry).
b) For the measure subsidizing the mowing of steep slope meadows (B51), we used the payment height applicable for slopes between 30-49 %
c) For the measure subsidizing alpine herding (B52), we used the payment height applicable for (accessible) alpine pasture units with a size smaller than 60 hectares.
d) For the measures subsidizing high-stem orchards (B57/H28/W07), payments are made per tree. As tree numbers per area are unknown, we calculated the payment

based on the Bavarian average per hectare (personal communication with the Bavarian Ministry of Food, Agriculture and Forestry).

e) For the measure subsidizing pasture grazing in summer (B60) payments are made per livestock unit. As those livestock units were unknown, we calculated the payment based on the Bavarian average per hectare (personal communication with the Bavarian Ministry of Food, Agriculture and Forestry).

Step 5: Validation of results

a) Due to the complex payment allocations and assumptions taken, the results are only an approximation of the actual payments. To validate our calculated payment heights, we compared them to a freely available dataset of payments per farm[2] (with indicated zip code). Payments for organic farming are listed as a separate category. Not considered in this "validation" dataset are the location of fields, which could be in a different zip code than the farm's address or even outside Bavaria. Our calculated payments and the "validation" dataset were aggregated per zipcode and then compared. Comparison of payments for organic farming:
   - Our calculated payments were 7.1 % lower than the "validation" data.

   The deviation could be due to (i) organic farms situated in Bavaria that have fields located outside of Bavaria or (ii) mistakenly removed payments for organic farming in "complicated combinations" (see step 2).
   - The correlation coefficient of payments per zip code area was 0.90

b) Comparison of total payments (without payments for grazing premiums, as they are most likely not included in the "validation" data):
   - Our calculated payments were 50.0 % higher than the "validation" data.

   This deviation could be due to (i) farms/payment receiver situated outside of Bavaria that have fields located in Bavaria or (ii) assumptions in the calculation of payment heights that lead to an overestimation. The mapped deviations per zip code show highest overestimates in two areas that are military training areas (payment receivers likely not based in Bavaria, or not included in the "validation data") as well as in the northern and southern border regions of Bavaria.
   - The correlation coefficient of payments per zip code area was also 0.90

[2] Payment data published by the German Federal Agency for Agriculture and Food (BLE) on the website: https://agrar-fischerei-zahlungen.de/. Combined dataset retrieved in 2022 from: https://farmsubsidy.org/

3. Classification of Agri-environmental schemes

We classified agri-environmental schemes into several categories based on their impacts on biodiversity and ecosystem services.

Table S1. Details on the classification of the agri-environmental schemes applicable to permanent grassland into classes used for the statistical analysis. KULAP = Cultural Landscape Program. VNP = Nature Conservation Program.

AES code	AES_description	AES program	AES scope	Area type	AES classification	Value for biodiversity[3]
B10	Ökologischer Landbau	KULAP	farm	all	organic farming	2a
B11	Ökokontrollverfahren	KULAP	farm	all	organic farming	2a
B20	Extensive Grünlandnutzung und max. 1,40 GV/ha HFF mit Verzicht auf Mineraldüngung	KULAP	branch of operation	grassland	extensive grassland mgmt.	2a
B21	Extensive Grünlandnutzung und max. 1,76 GV/ha HFF (Almen/Alpen) mit Verzicht auf Mineraldüngung	KULAP	branch	grassland	extensive grassland mgmt.	2a
B22	Extensive Grünlandnutzung und max. 1,40 GV/ha HFF (Almen/Alpen) mit Verzicht auf Mineraldüngung	KULAP	branch	grassland	extensive grassland mgmt.	2a
B23	Extensive Grünlandnutzung und max. 1,76 GV/ha HFF (Almen/Alpen) mit Verzicht auf Mineraldüngung	KULAP	branch	grassland	extensive grassland mgmt.	2a
B25	Emissionsarme Wirtschaftsdüngerausbringung (Eigenmechanisierung)	KULAP	farm	all	fertilization technique	3
B26	Emissionsarme Wirtschaftsdüngerausbringung (überbetriebliche Ausbringung)	KULAP	farm	all	fertilization technique	3
B28	Umwandlung von Ackerland in Grünland entlang von Gewässern und in sonstigen sensiblen Gebieten	KULAP	field	grassland	other	2a
B29	Umwandlung von Ackerland in Grünland in der Gebietskulisse Moore	KULAP	field	grassland	other	2a
B30	Extensive Grünlandnutzung entlang von Gewässern und in sonstigen sensiblen Gebieten, Verzicht auf jegliche Düngung und chemischen Pflanzenschutz (Förderkulisse)	KULAP	field	grassland	extensive grassland mgmt.	2a

[3] Based on: Horlitz T, Achtermann B, Pabst H, Schramek J (2018) Ermittlung des geplanten finanziellen Umfangs von Naturschutzmaßnahmen im Rahmen der ELER-Programme zur Entwicklung des ländlichen Raums 2014-2020 - Herausforderungen, Methode und Ergebnisse. 1 = high; 2 = medium; 3 = low.

B40	Artenreiches Grünland	KULAP	field	grassland	extensive grassland mgmt.	1a
B41	Grünland an Waldrändern	KULAP	field	grassland	extensive grassland mgmt.	1a
B49	Erneuerung von Hecken und Feldgehölzen	KULAP	field	all	other	1a
B50	Heumilch, (nur kombinierbar mit B20/B21/B10)	KULAP	branch	grassland	extensive grassland mgmt.	2a
B51	Steilhangwiesen (Erosionsschutz)	KULAP	field	meadow	other	1a
B52	Behirtung Almen/Alpen (jährliche Beweidung)	KULAP	field	pasture	other	1a
B59	Landschaftselemente	KULAP	field	all	other	1a
B60	Sommerweidehaltung	KULAP	branch	meadow	other	2a
F22	Schnittzeitpunkt 15.06. (Erschwernisausgleich)	VNP	field	meadow	extensive grassland mgmt.	1a
F23	Schnittzeitpunkt 01.07. (Erschwernisausgleich)	VNP	field	meadow	extensive grassland mgmt.	1a
F24	Schnittzeitpunkt 01.08. (Erschwernisausgleich) + ohne Düngung / chemischer Pflanzenschutz	VNP	field	meadow	extensive grassland mgmt.	1a
F25	Schnittzeitpunkt 01.09. (Erschwernisausgleich) + ohne Düngung / chemischer Pflanzenschutz	VNP	field	meadow	extensive grassland mgmt.	1a
F26	Mahd **bis** 14.06. Bewirtschaftungsruhe 15.06-31.08.	VNP	field	meadow	extensive grassland mgmt.	1a
F31	Extensive Weidenutzung	VNP	field	pasture	extensive grassland mgmt.	1a
F32	Extensive Weidenutzung (Almen)	VNP	field	pasture	extensive grassland mgmt.	1a
F33	Extensive Weidenutzung mit Ziegen	VNP	field	pasture	extensive grassland mgmt.	1a
H20	Umwandlung von Ackerland	VNP	field	grassland	other	1a
H21	Schnittzeitpunkt 01.06.	VNP	field	meadow	extensive grassland mgmt.	1a
H22	Schnittzeitpunkt 15.06.	VNP	field	meadow	extensive grassland mgmt.	1a

H23	Schnittzeitpunkt 01.07.	VNP	field	meadow	extensive grassland mgmt.	1a
H24	Schnittzeitpunkt 01.08.	VNP	field	meadow	extensive grassland mgmt.	1a
H25	Schnittzeitpunkt 01.09.	VNP	field	meadow	extensive grassland mgmt.	1a
H26	Mahd **bis** 14.06. und Bewirtschaftungsruhe bis 31.08.	VNP	field	meadow	extensive grassland mgmt.	1a
H27	Düngeverzicht	VNP	field	meadow	extensive grassland mgmt.	1a
H29	Brachlegung von Wiesen	VNP	field	meadow	extensive grassland mgmt.	1a
H30	Ergebnisorientierte GL-Nutzung	VNP	field	grassland	extensive grassland mgmt.	1a
H31	Extensive Weidenutzung	VNP	field	pasture	extensive grassland mgmt.	1a
H32	Extensive Weidenutzung auf Almen	VNP	field	pasture	extensive grassland mgmt.	1a
H33	Extensive Weidenutzung mit Ziegen	VNP	field	pasture	extensive grassland mgmt.	1a
N21	Verzicht Düng.	VNP	field	meadow	extensive grassland mgmt.	1a
N22	Verzicht auf Düngung (außer Festmist) und chem. Pflanzenschutz	VNP	field	meadow	extensive grassland mgmt.	1a
U02	Vorweide verboten	VNP	field	meadow	extensive grassland mgmt.	1a
U03	Frühmahdstreifen bzw. -flächen	VNP	field	meadow	extensive grassland mgmt.	1a
VNP	Alt-VNP	VNP	field	all	other	1a
W08	Verwendung eines Messermähwerkes	VNP	field	meadow	extensive grassland mgmt.	1a
W09	Verwendung von Spezialmaschinen	VNP	field	meadow	extensive grassland mgmt.	1a
W10	Verwendung von Motormäher	VNP	field	meadow	extensive grassland mgmt.	1a
W11	Handmahd	VNP	field	meadow	extensive grassland mgmt.	1a

W12	Zusammenrechen per Hand	VNP	field	meadow	extensive grassland mgmt.	1a
W13	Zusatzschnitt	VNP	field	meadow	extensive grassland mgmt.	1a
W14	Verpflichtender Erhalt von Altgrasstreifen/-flächen auf 5 bis 20% der Fläche	VNP	field	meadow	extensive grassland mgmt.	1a
W15	Feuchtezuschlag	VNP	field	meadow	other	1a
W16	Tierschonende Mahd	VNP	field	meadow	extensive grassland mgmt.	1a
W17	Bewirtschaftungsruhe ab 15.03. bzw. 1.4. bis zum vereinbarten Schnittzeitpunkt	VNP	field	meadow	extensive grassland mgmt.	1a
W18	Mitführen von Ziegen	VNP	field	pasture	extensive grassland mgmt.	1a
W19	Bewirtschaftungseinheit maximal 2 ha (Kleinflächenzuschlag)	VNP	field	pasture	other	1a

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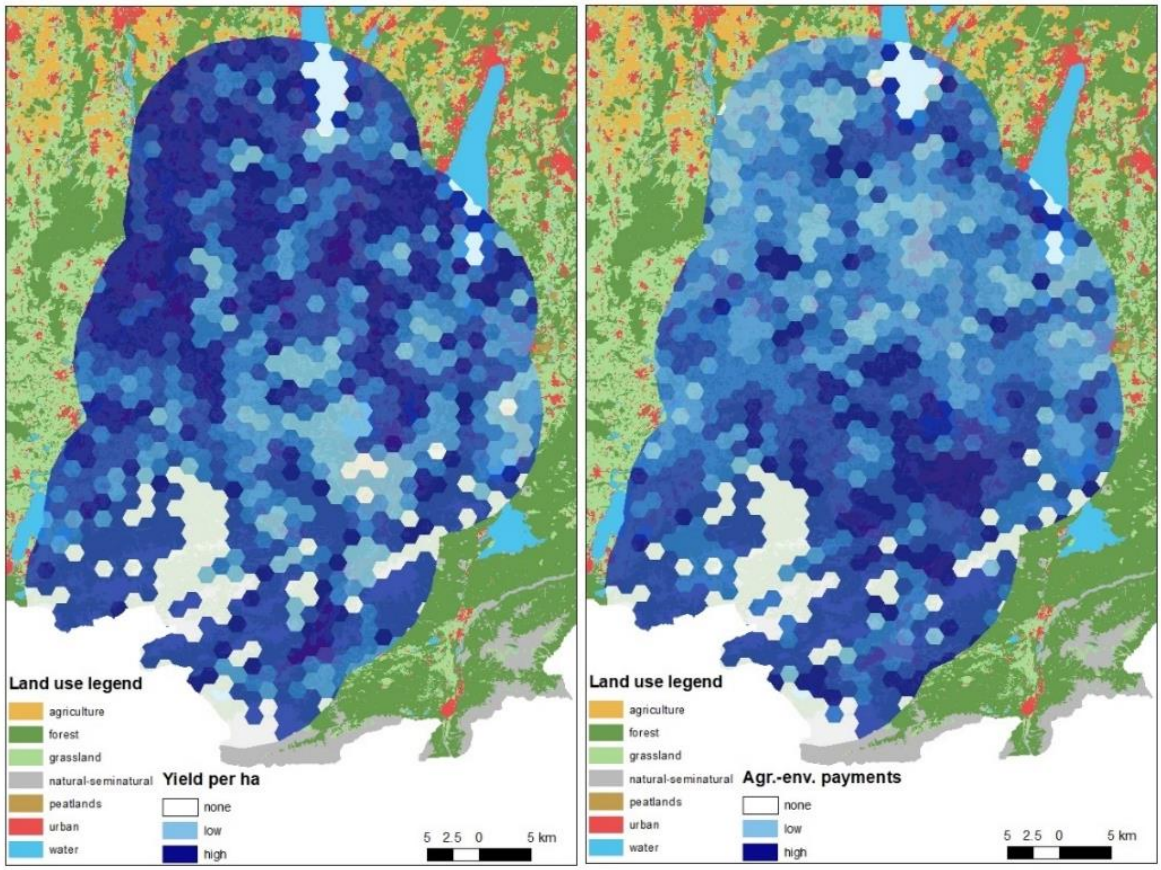
4. Individual visualization of grassland ecosystem service supply in the study area



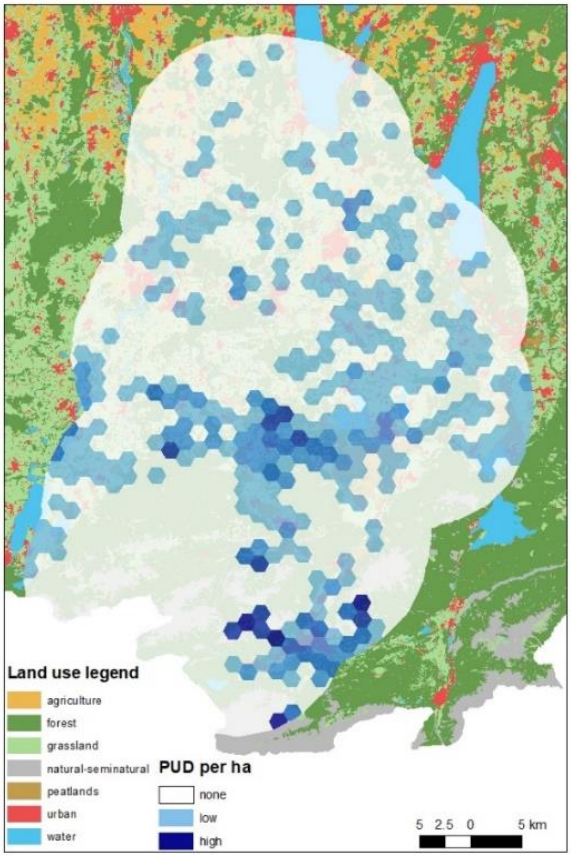


Figure S1. Distribution of yield (top left), agri-environmental payments (top right) and Photo-User-Days (bottom right) averaged to 2km-hexagon polygons.

5. Supply of regulating and habitat ecosystem services in the study area

The study used agri-environmental payemnts - substituting a loss of yield in favour of regulating ecosystem services and biodiversity - as an indictor for regulating and habitat ecosystem services. To descriptively compare the representativity of the indicator, the following figures provide an overview of ecosystem services supply in the study area, which are publicly available at the atlas of ecosystem services in Bavaria. For methodological information, please see http://atlas.oekosystemleistung.bayern.

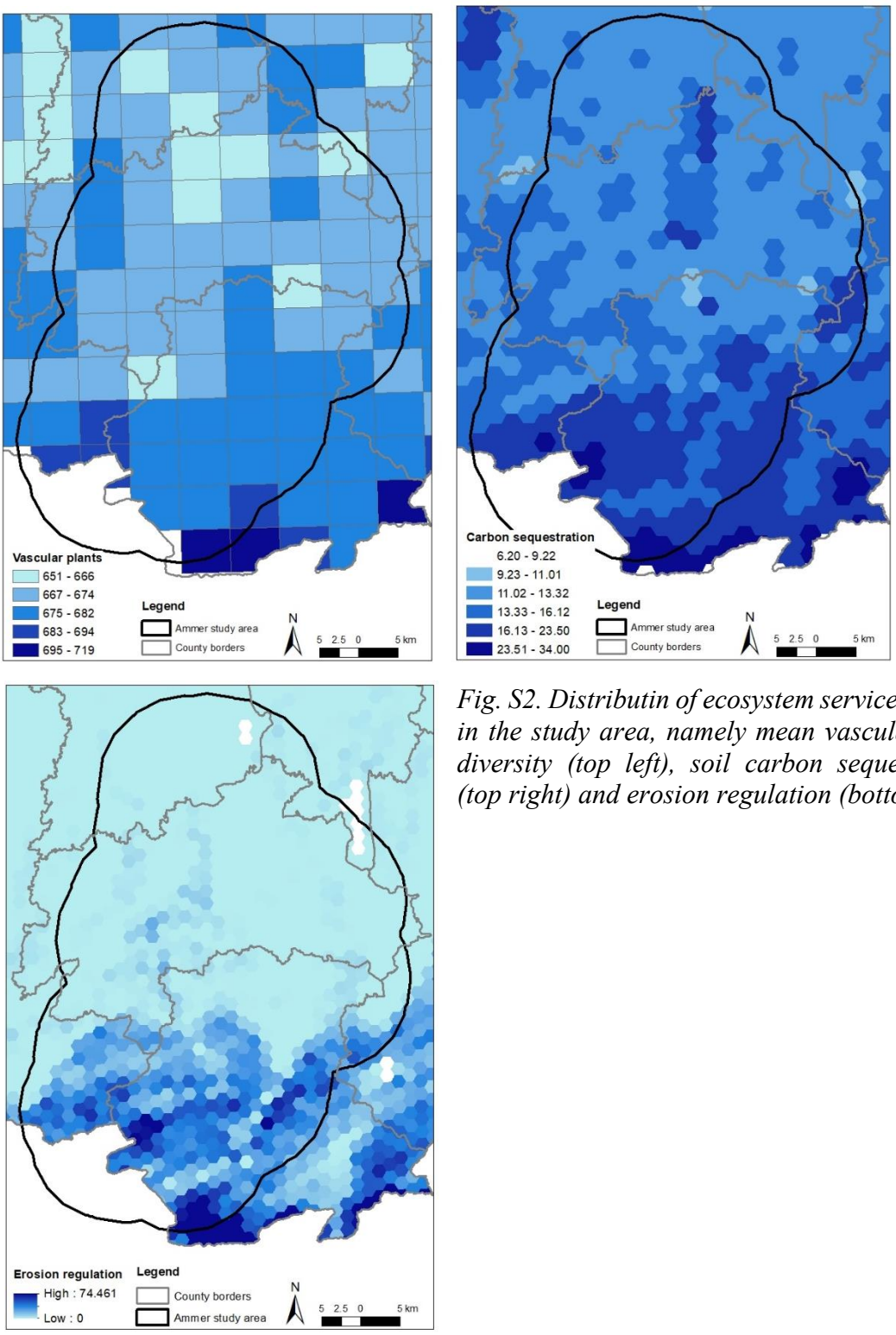


Fig. S2. Distributin of ecosystem services supply in the study area, namely mean vascular plant diversity (top left), soil carbon sequestration (top right) and erosion regulation (bottom left).

2.4 List of publications and declaration of individual contributions

2.4.1 Declaration of individual contributions to manuscripts that are part of this dissertation

Paper 1

Title: Ecosystem services from (pre-)Alpine grasslands: Matches and mismatches between citizens' perceived suitability and farmers' management considerations
Authors: Thomas M. Schmitt, Berta Martín-López, Andrea Kaim, Andrea Früh-Müller, Thomas Koellner
Journal: Ecosystem Services
Status: Published (2021)
Own contribution: Conceptualization 70%, data acquisition 70%, data analysis 90%, writing original manuscript 100%, review and editing 80%.
Description: The study was conceptualized by TMS, BML, and TK. Data was collected by TMS and further other members of the Professorship of Ecological Services (see chapter 3 acknowledgements). TMS analysed the data and wrote the first draft of the manuscript. All authors contributed to review and editing.

Paper 2

Title: Plural valuation in space: mapping values of grasslands and their ecosystem services
Authors: Thomas M. Schmitt, Rebekka Riebl, Berta Martín-López, Maria Hänsel, Thomas Koellner
Journal: Ecosystems and People
Status: Published (2022)
Own contribution: Conceptualization 70%, data acquisition 75%, data analysis 80%, writing original manuscript 100%, review and editing 80%,
Description: The study was conceptualized by TMS, BML and TK. TMS led the data analysis with contributions from RR, BML and TK. TMS wrote the first draft of the manuscript. All authors contributed to review and editing

Paper 3

Title: Recreation and its synergies and trade-offs with other ecosystem services of Alpine and Pre-Alpine grasslands
Authors: Thomas M. Schmitt, Maria Hänsel, Andrea Kaim, Heera Lee, Sophie Reinermann, Thomas Koellner
Status: Under Review (March 2023)
Own contribution: Conceptualization 75%, data acquisition 60%, data analysis 100%, writing original manuscript 90%, review and editing 70%,
Description: The study was conceptualized by TMS and TK with contributions of all authors. Data was prepared by TMS, MH, AK, HL and SR. TMS analysed the data. TMS led the writing process with sections in methods written by MH, AK, and SR. All authors contributed to review and editing.

2.4.2 List of all contributions to peer-reviewed scientific publications in ISI-listed journals

Küchen, L., **Schmitt, T.M**., Riebl, R., Haensel, M., Steinbauer, M. J., Fricke U., Redlich, S., Koellner, T., In Press. Where and why is landscape considered valuable? Societal actors' perceptions of ecosystem services across Bavaria, Germany. Ecosystems and People. doi.org/10.1080/26395916.2023.2192813

Haensel, M.*, **Schmitt, T.M.*,** Bogenreuther, J., 2023. Teaching the modeling of human-environment systems: Acknowledging complexity with an agent-based model. Journal of Science Education and Technology. doi:10.1007/s10956-022-10022-z *(*equal contributions).*

Thiemann, M., Riebl, R., Haensel, M., **Schmitt, T.M**., Steinbauer, M., Fricke, U., Redlich, S., Koellner T., 2022. Perceptions of ecosystem services: comparing socio-cultural and environmental influences. PlosONE. doi.org/10.1371/journal.pone.0276432

Schmitt, T.M., Riebl, R., Martín-López, B., Hänsel, M., Koellner, T., 2022. Plural valuation in space: Mapping values of grasslands and their ecosystem services. Ecosystems and People. https://doi.org/10.1080/26395916.2022.2065361

von Heßberg, A.; Jentsch, A.; Berauer, B.; Ewald, J.; Fütterer, S.; Görgen, A.; Kluth, S.; Krämer, A.; Koellner, T.; Scharmann, M., Schloter, M., **Schmitt, T.M**., Schödl, M., Schuchardt, M., Schucknecht, A., Steinberger, S., Vidal, A., Voith, J., Wiesmeier, M., Dannenmann, M., 2021. Almen in Zeiten des Klimawandels: Schutz der Artenvielfalt durch (Wieder-) Beweidung? Die Fallstudie Brunnenkopfalm im Ammergebirge. Naturschutz und Landschaftsplanung 53. doi:10.1399/NuL.2021.03.02.

Schmitt, T.M., Martín-López, B., Kaim, A., Früh-Müller, A., Koellner, T., 2021. Ecosystem services from (pre-)Alpine grasslands: Matches and mismatches between citizens' perceived suitability and farmers' management considerations. Ecosystem Services 49, 101284. https://doi.org/10.1016/j.ecoser.2021.101284

Hoffmann, S., **Schmitt, T. M**., Chiarucci, A., Irl, S., Rocchini, D., Vetaas, O.R., Tanase, M., Mermoz, S., Bouvet, A., Beierkuhnlein, C. 2018. Remote sensing of β-diversity : Evidence from plant communities in a semi-natural system. Applied Vegetation Science 22. https://doi.org/10.1111/avsc.12403

(Eidesstattliche) Versicherungen und Erklärungen

(§9 Satz 2 Nr. 3 PromO BayNAT)

Hiermit versichere ich eidesstattlich, dass ich dieArbeit selbstständig verfasst und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe (vgl. Art 64 Abs. 1 Satz 6 BayHSchG).

(§9 Satz 2 Nr. 3 PromO BayNAT)

Hiermit erkläre ich, dass ich die Dissertation nicht bereits zur Erlangung eines akademischen Grades eingereicht habe und dass ich nicht bereits diese oder eine gleichartige Doktorprüfung endgültig nicht bestanden habe.

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Bayreuth, März 2023

Thomas Schmitt