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ORIGINAL ARTICLE

Recreation and its synergies and trade-offs with other ecosystem services of Alpine and pre-Alpine grasslands

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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 the use of grasslands for cultural ecosystem services such as recreation. In this study, we investigated the synergies and trade-offs of ecosystem services and analyzed underlying variables related to the recreational use of grasslands. We investigated the supply of recreation (indicated by Photo-User-Days from geo-tagged photos on grasslands), fodder production (indicated by yield), and 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 use 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 the recreational use. 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 underscores the value of grasslands as a component of the cultural landscape for recreational purposes. 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

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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 provision of habitats for biodiversity (Bengtsson et al. 2019; Bardgett et al. 2021). 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 (Cocca et al. 2012; Monteiro et al. 2011; 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 can contribute to income, but are often non-substitutable to people (Howley et al. 2011, 2012, Junge et al. 2011, 2015; López-Santiago et al. 2014; Scolozzi et al. 2015; Bengtsson et al. 2020). An important concept for the study of cultural ecosystem services is co-production, which relates to the fact that ecosystem services can frequently be considered to be produced not only by natural factors, but by an interplay of natural, social, financial, or technological factors (Bruley et al. 2021; Palomo et al. 2016). This is particularly relevant for cultural ecosystem services, which are relatively complex to quantify and have only been gaining increasing attention in recent years. In forest management, the Recreation Opportunity Spectrum has evolved in the last decades and offers a framework to explain recreational opportunities in a certain area through a combination of independent factors, including the capacity of ecosystems to provide recreational services, but also accessibility factors (Byczek et al. 2018; Clark and Stankey 1979). Different methods have evolved to investigate underlying factors of the recreational value and recreational use of landscapes, such as stated preferences by means of surveys or interviews (e.g. Plieninger et al. 2013; Junge et al. 2015; Delgado-Aguilar et al. 2017). However, the time and effort needed for such stated-preference methods often reduce the feasibility to be applied in large-scale studies (Norton et al. 2012). As an alternative, crowd-sourced photos from platforms such as Flickr have been successfully applied in assessing cultural ecosystem services as a revealed-preference proxy (Figueroa-Alfaro and Tang 2017; Lee et al. 2022). The meta information obtained from crowd-sourced databases, 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 (Ghermandi 2022; Wood et al. 2020). In other (semi-natural) contexts, infrastructural and environmental factors were also assessed to be important underlying factors influencing photo locations (e.g. Havinga et al. 2021; Lee et al. 2022).

In previous studies that investigated landscapes valuable for aesthetic and recreational activities, intensively used croplands have been perceived to be less attractive than extensively managed landscapes (e.g. van Berkel and Verburg 2014; Kuechen et al. 2023). For instance, Lieskovsky et al. (2017) found in a study assessing geo-tagged photographs across Slovakia that landscapes used for intensive agriculture in lowlands had a low attractivity to people. Also, by investigating stated preferences of different societal actors in a central European case study, Kuechen et al. (2023) found that forests and grasslands were perceived as more valuable for cultural ecosystem services than cropfields. This is in line with findings from De Groot and van de Born (2003) arguing that "naturalness" of landscapes is a major contributor to landscape preferences. Besides the importance of naturalness of landscapes, previous analyses have also illustrated the strong influence of cultural attractions on recreational activities in landscapes. Wood et al. (2020), for instance, showed that cultural attractions can be even more important than natural features.

Despite the strong evolvement in literature regarding the impact of various factors on the perception of landscape aesthetics and recreational activities, and common findings that grasslands are perceived as very attractive for recreational activities, there is a gap in knowledge concerning the specific grassland types and management regimes relevant for recreational activities related to grasslands (Bengtsson et al. 2019). There is a great variety of grasslands ranging from natural landscapes to highly managed agricultural land. 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). Therefore, gaining a better understanding of the underlying factors of recreational use of grasslands is crucial. Disentangling this is specifically relevant for grasslands, as some previous studies suggested that aesthetic preferences of visitors are higher in grasslands that have high biodiversity levels (e.g. Junge et al. 2015), while other studies suggest that intensively managed grasslands can also provide high cultural ecosystem services (e.g. Le Clec'h et al. 2021).

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, further research is needed in identifying underlying mechanisms of trade-offs and synergies between provisioning, regulating, and cultural services. Analyses on trade-offs and synergies of grassland ecosystem services should specifically be conducted using multiple methods including different types of data acquisition (Zhao et al. 2020). Thus, this study aims to deepen the knowledge on the relationships between ecosystem services in Alpine and Pre-Alpine grasslands and, specifically, unravel the role that grasslands play in recreational use.

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) analyze how additional infrastructural, environmental, and policy mechanisms are related to recreational use of grasslands; and finally (3) explore spatial patterns of recreation in the study area. We hypothesize that extensively managed grasslands are more frequently used for recreation 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 other natural features in the surroundings of the grasslands as well as proximity to cultural factors such as the presence of castles, cable cars, or hiking trails, strongly influence the recreational use of grasslands (Lieskovský et al. 2017; Wood et al. 2020).

Methods

Study area

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 the highest peak in Germany, "Zugspitze", with an altitude of 2969 m.a.s.l (NASA, 2009). The mountainous part further includes sections of the Wetterstein mountains, Ammergau Alps, and Bavarian Prealps. The study area is the watershed of the river Ammer, including an additional buffer to eliminate potential edge effects, and consists of agricultural land (36%), forests (41%), lakes (5%), settlements (4%), and other land covers (14%), including mountainous rock and peat environments (Fig. 1) (LDBV, 2016). With 71% of its agricultural land use, the study area is strongly shaped by grasslands, providing a profound case study for the analysis of grassland ecosystem services. Grassland 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, mountainous part of the study area, which frequently provides additional income for otherwise less economically profitable agricultural activities (Ammergauer Alpen GmbH 2017).

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

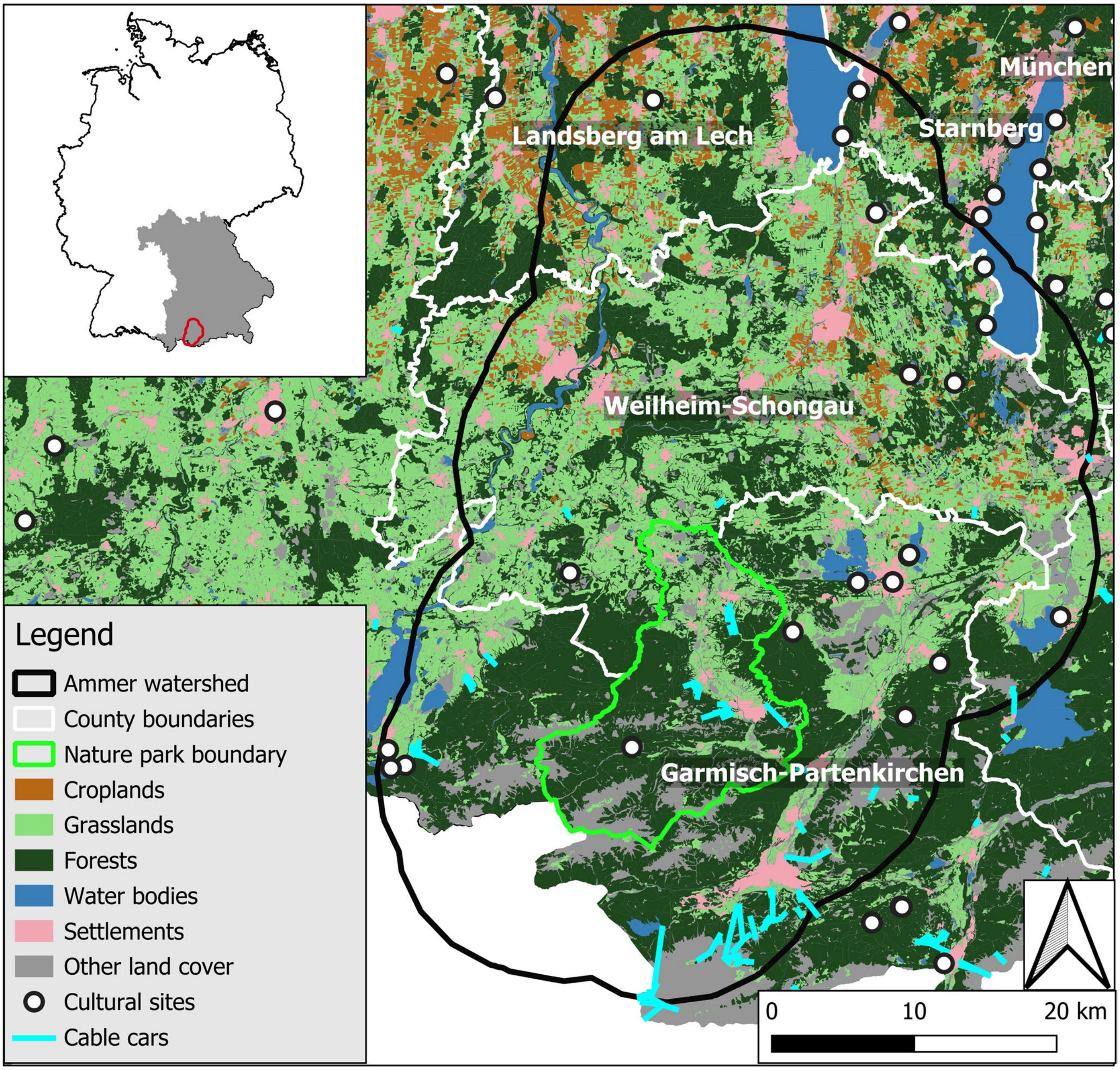

Fig. 1 Location and details of the study area in Bavaria, Germany

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 the number and types of livestock.

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

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 2 km 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 100 m around grasslands [yes/no]	ATKIS (2018)[2]
	Cycling trails	Presence 100 m around grasslands [yes/no]	
	Mountain bike trails	Presence 100 m 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)

data to automatically detect cutting events in grasslands. The timing and frequency of cutting events derived from the satellite data (Sentinel-2) were aggregated from pixel-resolution (10 m × 10 m) 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 2.1% of all grassland fields. 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 due to less water availability, less solar insolation, and limitations in mechanization.

Photo-User-Days

A popular indicator for assessing cultural ecosystem services, specifically recreation, is 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. 2018). 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 (Levin et al. 2017; Oteros-Rozas et al. 2018; Sonter et al. 2016). 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 (Fox et al. 2020) on February 7th, 2022. We selected the photos taken on or within a 100 m buffer around grasslands ($n=1590$) assuming that photos taken within these boundaries relate to the surrounding grasslands (Le Clec'h et al. 2019; Schirpke et al. 2018). This recreational use of grasslands could either be based on depicting grasslands on the photo or by acknowledging the openness of grasslands and picturing other natural or cultural features. Secondly, we derived 1082 PUD to avoid the bias of some users taking multiple photos on the specific location and the same day. 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 Conservation Program). These schemes are paid to compensate for the loss of yield on a field in favour 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 specific 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-environmental schemes as independent variables provide additional information. They are also independent of the amount of the subsidy 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).

Statistical and spatial analyses

For the statistical and spatial analyses, we *z*-standardized all numerical variables (Fig. 2). First, we conducted Spearman's Rho (package *stats* in R) 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

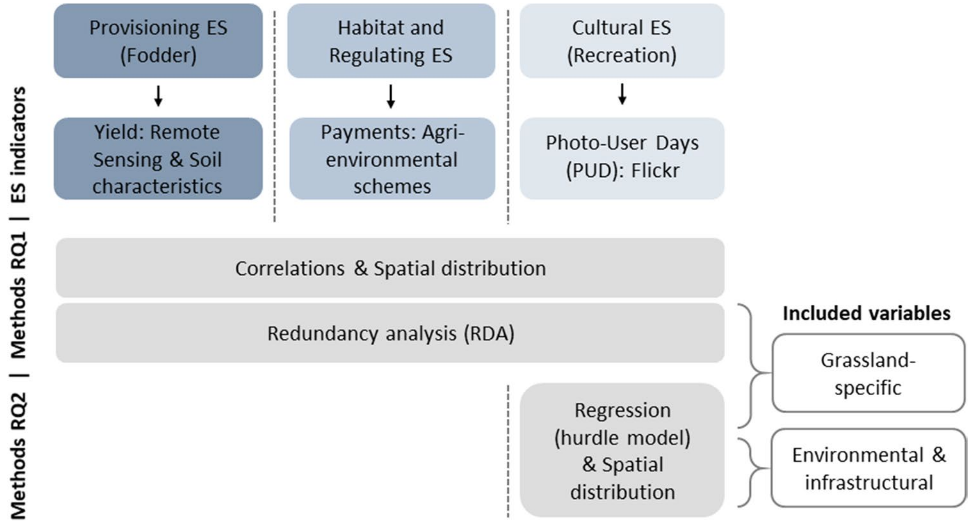

Fig. 2 Analysis flow chart. Blue boxes show calculation of ecosystem service indicators (dependent variables); white boxes illustrate independent variables included in the analyses; grey boxes show statistical and spatial analyses conducted. ES = ecosystem services; PUD = Photo-User-Days; RQ = research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

for 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 tests (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, to better understand the role of grasslands for recreational use, we visually screened a subset of the photos. For this analysis, 20% of the photos ($n = 516$) were randomly selected and the content of the photos systematically analyzed about (i) if grasslands were present on the photo, (ii) whether grasslands were a major element on the photo, (iii) if the grasslands were covered with snow, and (iv) other features or recreational activities present on the photo.

Fifth, 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*) in R to determine the optimal bandwidth of kernels (299). All grassland fields in the study area were defined as the window of observation, without the additional buffer of 100 m that had been used to collect the photos. Finally, to determine clusters of PUD on grasslands with high numbers of pictures taken, we employed Getis-Ord Gi* statistics (Getis and Ord 1992), conducted in ArcGIS.

Results

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. Spearman's rank (p-value < 0.05; rho $= -0.012$) 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 Fig. 3, the northern part of the study area shows higher yields per ha than the southern part of the study area when averaged on a 2 km hexagon grid. 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).

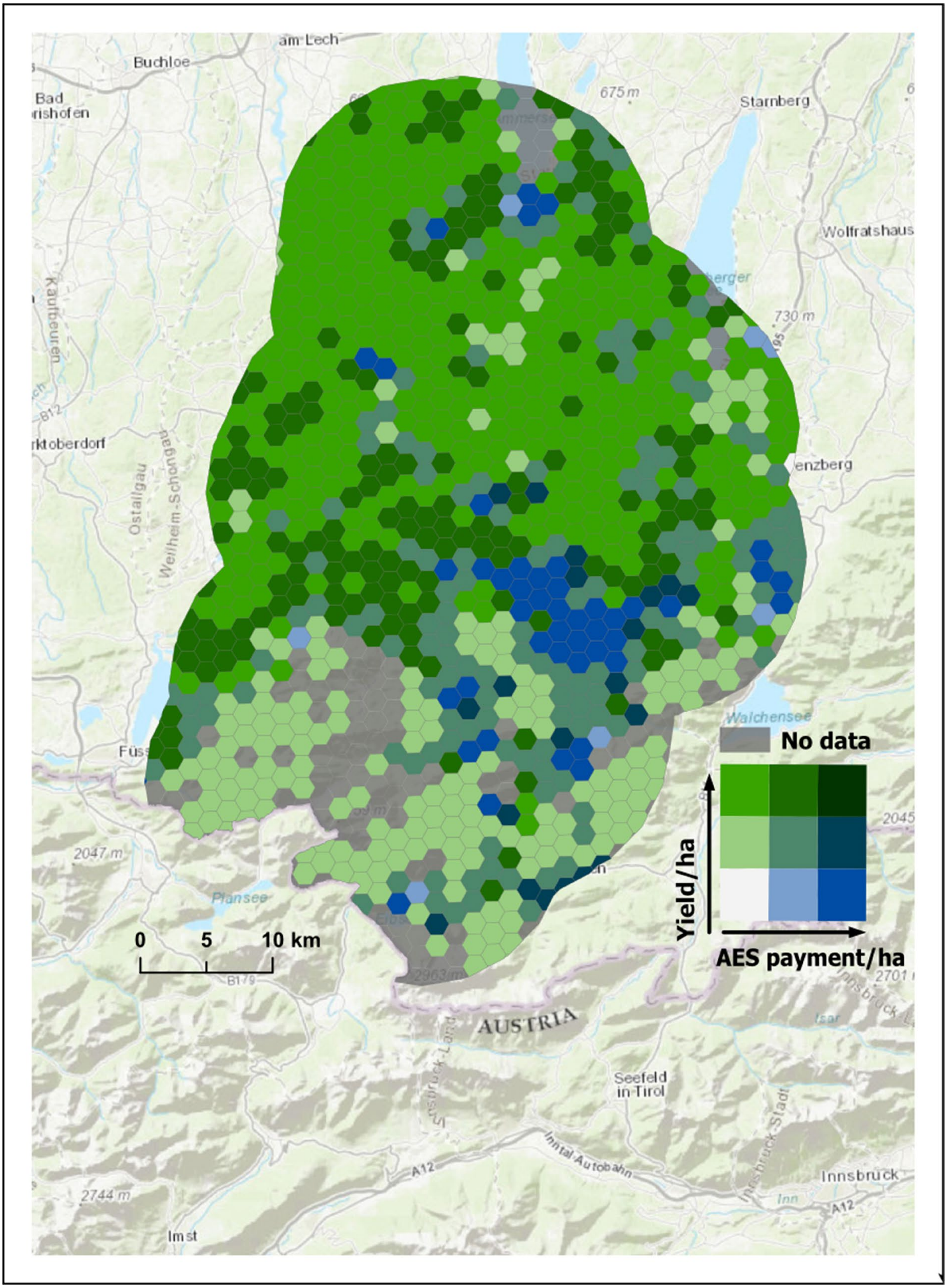

Fig. 3 Spatial distribution of provisioning ecosystem service (Yield/ha) and regulating/habitat ecosystem service (AES payment/ha) indicators presented in a 2-km hexagon grid. AES = agri-environmental schemes

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

The Redundancy Analysis (RDA) indicated a statistically significant relationship between grassland management variables and indicators of ecosystem services (Table 2). The analysis also supported the previously described significant but low negative correlation between PUD and yield. The first axis of Fig. 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 ha 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.

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 PUD. The proportion of croplands in the surroundings of the photos taken negatively influenced PUD. 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 recreational use of grasslands, so did dairy cow farming (see Table 3).

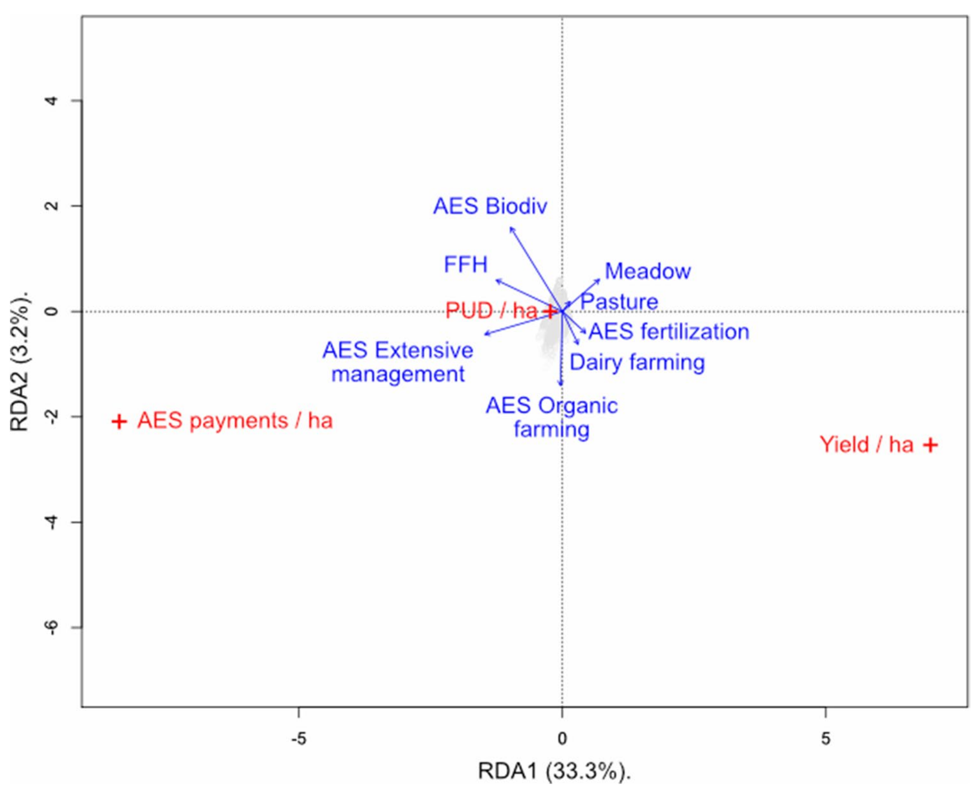

Fig. 4 Redundancy Analysis (RDA) of grassland characteristics (blue) and indicators for ecosystem services (red). FFH = Flora-Fauna-Habitat sites; AES = Agri-Environmental Schemes; PUD = Photo-User-Days

Table 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

The screening of the photos revealed that a large proportion of the screened photos depicted grasslands in some form (41%), while the remaining photos mainly included other landscape elements such as forests or buildings. Only few photos could not be associated with use of grasslands for recreation at all, namely photos taken indoors (see Table 4). Photos that did not picture grasslands might still be used for recreational purposes on grasslands, for instance as they provide the space for tents in cultural events or for providing view of the surrounding landscape. Out of the photos that depicted grasslands, on 27% of these we identified the grasslands to be a major feature, while 23% were covered with snow.

Spatial distribution of grasslands with PUDs

The Kernel density plot (Fig. 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 the "Zugspitze" mountain.

Discussion

In this study, we found that people slightly use extensive grassland over intensive grassland for recreation, but infrastructural and environmental variables also play a fundamental role in explaining visitation rates. In the following section, we discuss the use of grasslands for 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 the recreational use of grasslands. We lastly discuss limitations to the explanatory power of the study.

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 at the same time 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

Table 4 Proportion of photos that included one of the following features in the screened photo sample ($n = 512$)

	Natural and socio-cultural features											
	Flower	Forest	Mountain	Rock	Surface water	Grazing	People	Tent	Street	Vehicles	Building	Indoor
Photo with grasslands	5%	77%	62%	0%	6%	5%	5%	0%	11%	7%	41%	0%
Photo without grasslands	7%	28%	17%	17%	21%	0%	10%	6%	3%	3%	27%	18%

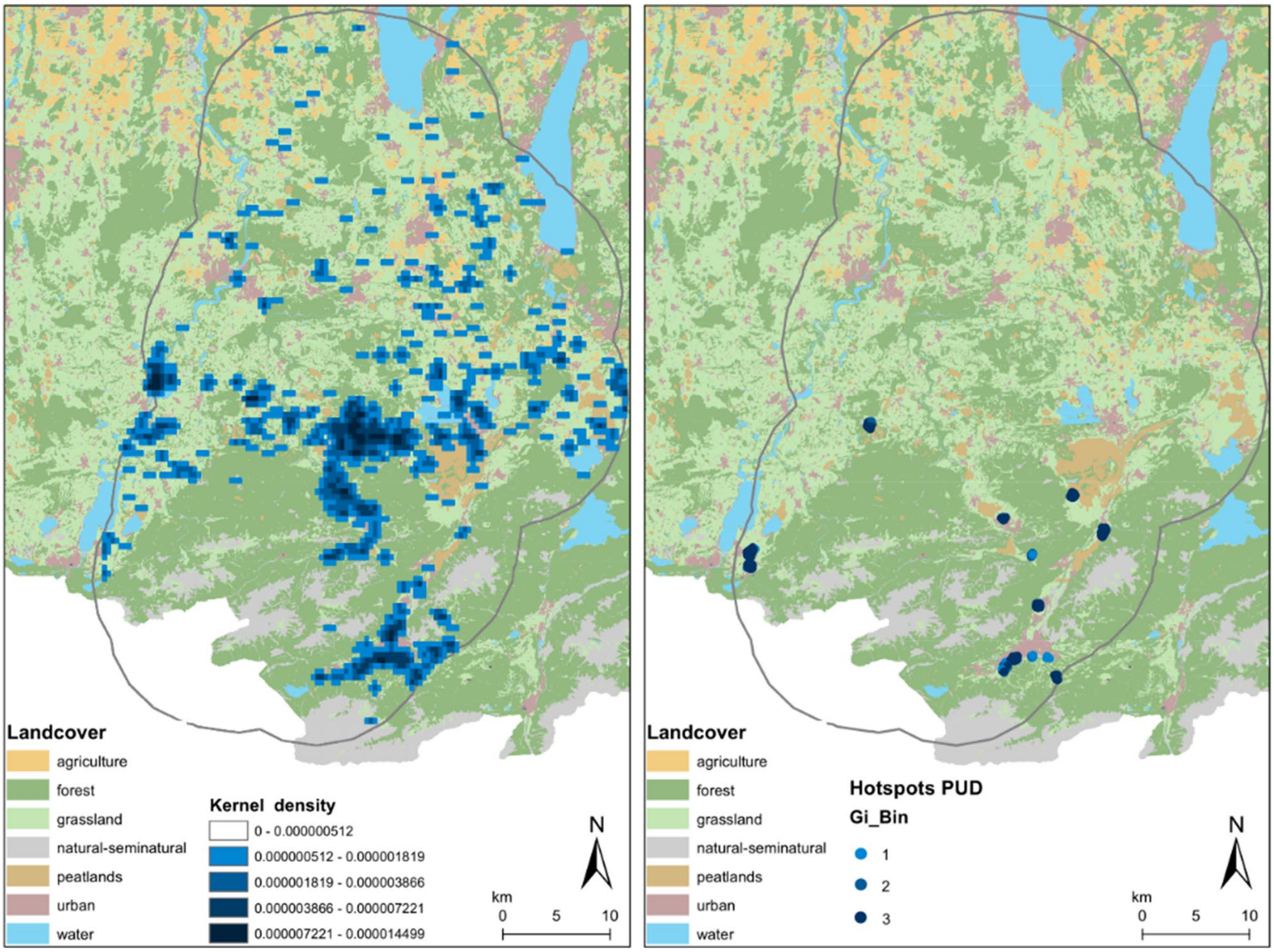

Fig. 5 Spatial distribution of grasslands with at least one PUD (left) based on Kernel density and grasslands with high numbers of PUD of grasslands (right) based on Getis-Ord Gi* hotspot analysis. Gi_Bin identifies statistically significant hotspots based on a confidence interval of 99%, (features with Gi_Bin + 3), 95% (features with Gi_Bin + 2), and 90% (Gi_Bin + 1)

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 labour and low productivity, while in the valley bottoms meadows are continuously intensified (Cocca et al. 2012; Monteiro et al. 2011). 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 varies in the study area from less than 6000 kg per cow and year in the southern part to more than 7000 kg per 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 Rho. Le Clec'h et al. (2019) found trade-offs between yield and recreation in extensively used grasslands only, but not in intensively managed ones. On the other hand, 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 grasslands used for recreation was only observed in the binary model. This also relates to the weak negative relationship of the 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 on grasslands that are not visited and other factors strongly influence PUD.

Explaining recreational use of pre-Alpine and Alpine grasslands

Our results revealed that besides fodder production, environmental and infrastructural variables influence recreational use of 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 the 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. 2021, 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 use. 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 affect visitation rates and provide higher attractivity of grassland (Junge et al. 2015). It is notable that both influential variables, namely grassland location in areas of high grassland share or in the Nature Park Ammergau Alps, are based in 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 hay 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 (Lee et al. 2022; Oteros-Rozas et al. 2018), 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. This is also supported by the screening of the photo content, revealing a heterogeneity in the recreational use of grasslands. It is not certain if the grasslands played a major role in the peoples' mind even when depicting grasslands. On the other hand, when grasslands were not depicted, they could still play a major role in recreational use as they may contribute to the openness of the landscape or as a ground for cultural activities (e.g. for tents). 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, which entails that the ecosystem services are not only produced by natural processes, but by a mixture of natural, social, financial, and technological factors (Bruley et al. 2021; 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 recreational use of 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). The acknowledgement that cultural ecosystem services are co-produced is particularly relevant for grasslands as they entail both high "naturalness", but also create an open cultural landscape in combination with cultural features (e.g. castles, churches, agricultural management). In a study by von Heßberg et al. (2021), for instance, visitors on Alpine pastures have articulated the necessity of both natural features such as wild flowers and trees, but also grazing cattle to exist in the landscape, co-producing the recreational value.

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 use of grasslands for recreational activities.

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 recreational use of 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 recreational uses 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, quantifying recreational use of grasslands can provide useful insights for visitor planning and management (Schirpke et al. 2020; 2014). 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.

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 can entail uncertainties. 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 (southern mountainous region), there is also a specifically high supply of carbon sequestration and erosion regulation. Additionally 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 were made 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, which might be a source of uncertainty depending on the investigated region. In addition to that, 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. 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-sourced 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 (Wilkins et al. 2021; Wood et al. 2020). We also acknowledge that there could be differences in the seasonal patterns of photos (Schirpke et al. 2018), which limits this studys' 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 photos and tags with artificial intelligence or by qualitative analyses, could limit the assumptions mentioned (Egarter Vigl et al. 2021).

Further analyses on the content of photos 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. Such analysis could further identify the specific recreational activities on grasslands, which was not possible with the screening of the photos as only on few photos specific activities were depicted. Looking into these aspects in more detail 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. Concerning the influence of the surrounding land uses, further spatial analyses could be of interest. We decided not to conduct additional analyses on the intensity of agricultural management of the surrounding land uses, but only the land use type, as the intensity is not easily observable in grasslands from a distance (e.g. fertilization input, number of cuts), but such factors could be of interest in more heterogenous landscapes that are not as dominated by grasslands.

Conclusion

Based on the results of this study, we conclude that grasslands play an important role for recreational use in pre-Alpine and Alpine settings. Extensively managed grasslands showed a slightly higher potential for recreational use 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 were found to be used for recreational purposes, however mainly in combination with other contextual factors, including both natural and cultural features. The results imply that recreation on grasslands can be fostered by policy instruments such as targeted agri-environmental schemes and protected areas. The study also concludes that recreational use of (pre-)Alpine grasslands is weakly but significantly negatively correlated with yield outputs, illustrating the need to maintain extensively used grasslands in this environment. 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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