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Towards an integrative assessment of land-use type values from the perspective of ecosystem services

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ABSTRACT

Policy-makers and practitioners are increasingly interested in information about ecosystem services (ES), but the creation of indicators that are comprehensive and yet interpretable for stakeholders remains a challenge. In this study, we make use of the extensive body of research on ES and available data to quantify the value of land-use types from an ES perspective. Specifically, we estimate the supply of 19 important ES for the main land-use types on the basis of 58 ecosystem and landscape measures (capturing either state, quantity or process) derived from the literature. In addition, we used survey-based evidence of socio-cultural values of ES to integrate society's demand for ES. Our approach allows for an integrative assessment and comparison of land-use types, considering both the supply and demand of multiple ES, and the production of outputs at three levels of aggregation, relating to (1) individual ES, (2) ES categories, and (3) land-use types. This makes it possible to flexibly adapt outputs according to the needs of stakeholders, while balancing concerns of comprehensiveness and ease of use. We conclude with a discussion of further avenues for future research, calling for a stronger coordination of ES research and the establishment of shared databases on ES.

1. Introduction

Society and its well-being are closely linked to natural capital (Burkhard and Maes, 2017; Díaz et al., 2018). Nature offers a multitude of goods and services that are essential to enable and support social and economic development. The importance of these ecosystem services (ES) has increasingly become the focus of political thinking over the last decade (Guerry et al., 2015), leading to increased interest in information from ES assessments by decision-makers (van Oudenhoven et al., 2018). Since the Millennium Ecosystem Assessment (2005), numerous initiatives have been launched at the regional, national and international level for the protection, conservation and enhancement of natural capital and the resulting ES for human well-being. Among the most important initiatives are the multi-level assessments under the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the UN guidelines on experimental ecosystem accounting from the System of Environmental-Economic Accounting (UN SEEA EEA), the Mapping and Assessment of Ecosystem and their Services (MAES) initiative in the framework of the EU Biodiversity Strategy towards 2020, and the 7th Environment Action Programme (7th EAP) of the European Union.

These initiatives, as well as the extensive research on ES carried out in recent decades, have contributed considerably to our understanding of ES. First, ES are multiple and typically produced as bundles, which makes the consideration of the full range of services necessary in order to avoid incomplete and potentially misleading management and planning recommendations (Howe et al., 2014; Mouchet et al., 2017a). Second, ES result from the complex interaction of ecological and social systems, as connections between ecosystem processes, functions and benefits to humans are multi-layered, non-linear and dynamic (Jones et al., 2016; Costanza et al., 2017). This underlines that effective ES assessments must take into account both the complex relationships between ecosystem processes, structures and capacities for ES provision (the supply), and the distribution and valuation of benefits between stakeholders with different needs and desires (the demand) (García-Nieto et al., 2013; Bennett et al., 2015; Wolff et al., 2015).

To address the idiosyncratic characteristics of individual ES, a variety of ES-specific approaches and indicators have been developed for the quantification and mapping of their supply, based on varying methods, data types, and spatial scales (Feld et al., 2010; Egoh et al., 2012; Layke et al., 2012; Bagstad et al., 2013; Schägner et al., 2013). Whereas most provisioning services are tangible goods that can be

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quantified through direct measurements at local to global scales, regulating services emerge from complex ecological functions or processes and are therefore primarily quantified based on direct and indirect measures reflecting various ecosystem conditions (Layke et al., 2012; Maes et al., 2016). Cultural services, by contrast, arise from people's interaction with their biophysical surroundings, making them difficult to assess in a biophysical manner across large spatial scales and requiring the direct involvement of local beneficiaries for their quantification (Hernández-Morcillo et al., 2013; Zoderer et al., 2016a). To estimate the potential for cultural ecosystem service provision, it is therefore essential to not only consider the biophysical characteristics of landscapes or ecosystems, but also how such characteristics are perceived by beneficiaries (Scholte et al., 2018). Tailoring specific methods to the particularities of individual services, however, means that assessments of ES supply are generally cost-intensive and time-consuming. As a result, most studies focus on only a few ES (Seppelt et al., 2011; Egarter Vigl et al., 2017) and thus rarely provide comprehensive multi-criteria ES assessments taking the full spectrum of relevant ES into account (but see for example Crouzat et al., 2015, Mouchet et al., 2017b). The resulting fragmentation of results makes it not only difficult for policy-makers and stakeholders to identify and collate relevant outputs, but omits critical information on the interactions between ES.

To provide policy-makers and stakeholders with relevant information on multiple ES, land-use types can serve as a central unit of inquiry and provide a common language accessible to both practitioners as well as the scientific community. Land-use types are of particular relevance for landscape planning and management as changes in land-use can directly be steered through both financial measures and planning interventions. In addition, a focus on land-use types as a central unit of analysis can further enable the systematic investigation of corresponding socio-ecological systems that are of particular scientific interest (Turner et al., 2003; Jones et al., 2016; Egarter Vigl et al., 2017). Building on the central premise of ES research that land-use types are ecologically more sustainable and socio-culturally preferable if the well-being of many people can be sustained by providing multiple ES (de Groot et al., 2010), the assessment of land-use types can be based on a multi-criteria assessment of the ES provided. Thus, individual land-use types are assigned highest value if they are characterised by a high multifunctionality of their system. Such an understanding is of particular relevance for policy-makers but also land managers and secondary users to achieve a sustainable management of land resources with the aim of preserving the supply of ES and making them available in a sustainable way (Rounsevell et al., 2012).

So far, studies that have captured the value of land-use types from the perspective of multiple ES and translated this information into outputs that are easy to understand for policy and decision-makers remain rare. The few existing studies have typically relied on expert judgements as a fast, flexible and cost-effective method. Specifically, rule-based models such as 'the matrix model' proposed by Burkhard et al. (2009, 2012) have been used to link aspects of land cover and use to different capacity levels of ES provision based on qualitative expert judgements (e.g. Stoll et al., 2015; Campagne et al., 2017). While acknowledging their advantages, qualitative expert estimates often remain imprecise and are ill-suited for capturing less tangible services that predominantly depend on the subjective appreciation by users (Jacobs et al., 2015). Furthermore, existing approaches do not fully synthesise insights from individual ES into one comprehensive output per land-use type but continue to communicate their results in the form of several individual indicators. For policy purposes and to facilitate comparisons across land-use types for practitioners, however, an aggregate output that is comprehensive and yet easy to understand is preferable (Müller and Burkhard, 2012).

This study proposes an alternative approach to quantify the value of land-use types from the perspective of multiple ES, building on the extensive body of available data and research on measures and indicators of ES. Through making use of the accumulated knowledge and data on ES, it becomes possible to address both their multiplicity and complexity without relying on the simplistic assumptions inherent in expert judgements. Specifically, we aim to collect and synthesise the large amount of data gathered in the well-studied region of the European Alps to assess the main land-use types with regard to their ES supply and demand. Furthermore, the approach developed in this paper enables the creation of outputs at different levels of aggregation – single ES, ES categories, and land-use type, thus being flexibly adaptable to the needs of stakeholders.

The paper is structured as follows: We first present the conceptual approach of our study and describe the individual methodological steps required to estimate land-use type values. Based on our findings, we suggest that ES research benefits from initiatives to collect and combine existing measures and indicators to allow a comprehensive assessment of several ES for important land-use types. We conclude by reflecting on the strengths and limitations of the proposed method and provide concrete recommendations for further action.

2. Material and methods

2.1. Study area

The study was carried out in the cross-border region of Tyrol, including the federal state of Tyrol in Western Austria and the Autonomous Province of South Tyrol in Northern Italy (Fig. 1). Located in the Central and Eastern Alps, the region covers a total area of 20,036 km^2, with elevations ranging from 194 m and 3905 m a.s.l. The region is predominantly covered by forests (42.9%), alpine grasslands (12.7%), rocks and glaciers (16.0%). Utilised agricultural areas cover 25.0% of the study area, whereby 8.6% are covered by intensively used hay meadows, 14.9% by extensively used hay meadows and pastures, 0.3% by arable farmland, and 1.2% by permanent crops used for apple and wine production. 3.3% of the study region refers to built-up areas and 0.1% to rivers, lakes and wetlands (data sources: Rüdisser et al., 2012, 2015). As is characteristic of mountain areas in general, land use in the study area is closely linked to elevation (as a proxy for the altitudinal climate gradient), slope inclination, and slope aspect. Whereas permanent crops can mainly be found in climatically favourable locations at elevations of up to 1000 m a.s.l. and intensively used hay meadows on the remaining productive and easy to access slopes on elevations up to 1600 m a.s.l., pastures and non-fertilised hay meadows are predominantly restricted to the less productive, harder to access slopes located on higher elevations. Against this background, the following seven main land-use types were identified and placed at the core of this study: permanent culture, arable land, fertilised hay meadows, non-fertilised hay meadows, low-intensity pasture, abandoned land, and forest.

2.2. Methods

The methodological approach developed in this study consists of several steps (Fig. 2). In a first step, we identify the most important ES in the Alpine region based on interviews, workshops and a literature review. To determine ES demand, we then use the results of two questionnaire surveys about people's socio-cultural values of ES. We collect land-use specific measures from data sources to capture state, quantity or process of ecosystems and landscapes. Based on these measures, we derive ES supply indicators for the main land-use types of the Alpine region. The value of land-use types is estimated by integrating information gathered on both ES supply and ES demand. Finally, similarities between land-use types are explored regarding their ES supply–demand patterns.

Before describing the individual steps in more detail, it is necessary to clarify our conceptualisation of the terms 'measures' and 'indicators'. Following the definition of Reyers et al. (2010), we define measures as

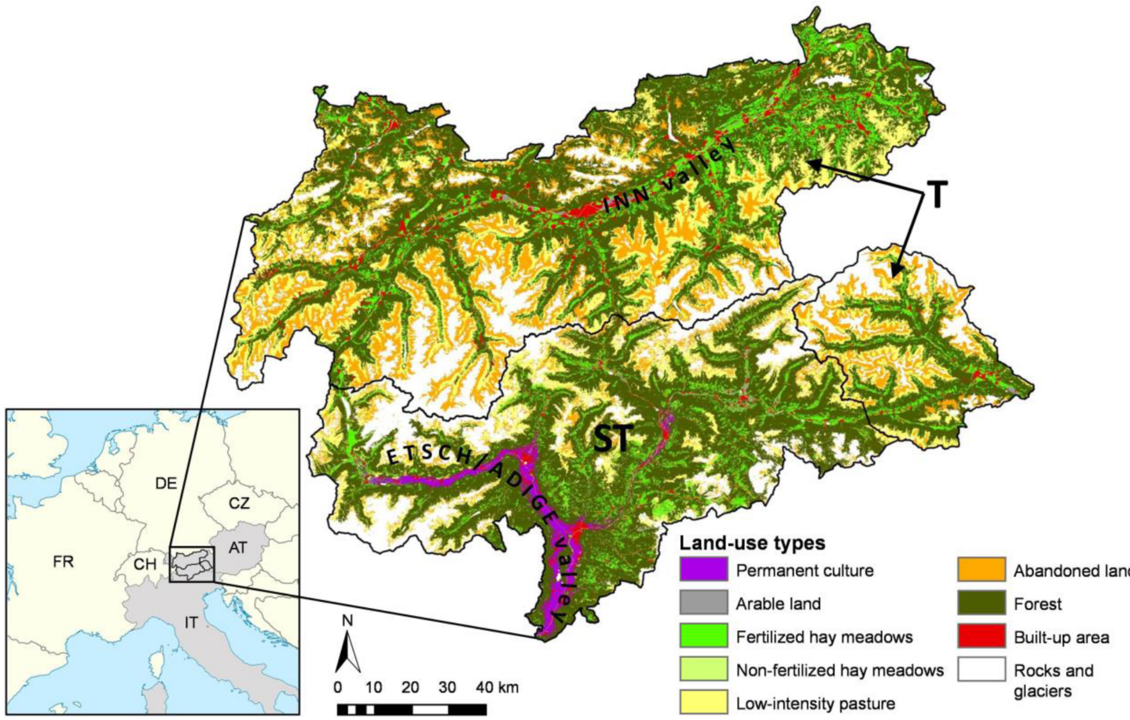

Fig. 1. The study area of the cross-border region of Tyrol (47°36′–46°02′ N and 10°08′–12°45′ E) displaying the main land-use types. T = federal state of Tyrol (Austria), ST = Autonomous Province of South Tyrol (Italy).

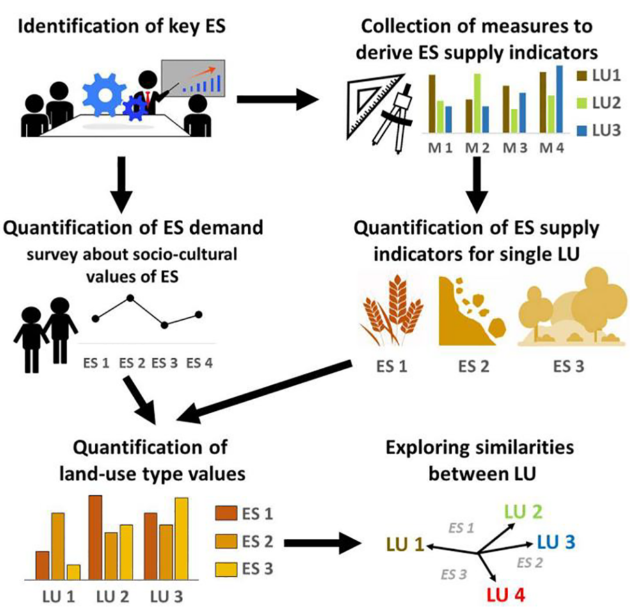

Fig. 2. Conceptual approach of the study to estimate land-use type (LU) values by integrating both ES supply and ES demand.

either a state, quantity or process of ecosystems and landscapes derived from direct observations, modelling outputs, statistical analysis or public surveys. In most cases, these measures correspond to the ‘condition indicators’ introduced by Maes et al. (2018), indicating either the biological, chemical or physical characteristics of ecosystems. In contrast, ES indicators highlight the capacity of ecosystems to provide provisioning, regulating, and cultural services. They are usually estimated based on measures and used for a specific purpose, for example to provide policy-makers with information about progress towards a specific goal (TEEB, 2010). In this study, we estimate the value of land-use types considering indicators for ES supply as well as ES demand.

2.2.1. Identification of key ES

The first step involved the careful selection of key ES which are the most relevant for the Alpine region. Based on three regional studies (Bacher et al., 2012; Fontana et al., 2013; Zoderer et al., 2019a) and a literature review (Table A.1), 19 important ES (classification according to CICES V5.1) provided by Alpine landscapes were selected (see Fig. 3). In Bacher et al. (2012), 19 semi-structured interviews were conducted with experts from different working fields and scientific disciplines, including ecology, landscape research, agriculture and sociology in order to identify important ES especially in the context of mountain agriculture. Fontana et al. (2013) discussed the most relevant ES of forests and grasslands in a workshop with 10 experts (i.e. forestry planning, hunting and fishery, landscape conservation, agriculture, tourism, mountain agronomy, nature conservation, and research). Zoderer et al. (2019a) conducted 25 interviews with experts but also with local farmers, residents and visitors to identify the most important ES for society. Finally, interviews and workshops were complemented by a literature review of ES studies conducted in the Central Alps. We looked for articles (up to June 2016) through *Web of Science* using the search string ((Alps OR Alpine) AND (“ecosystem service*” OR “landscape service*”)). We selected all studies specifically carried out in the Central Alps, focusing on the supply and/or demand of ES. For more details see Table A1.

2.2.2. Collection of measures to derive ES supply indicators

Building on the conceptual distinction between measures and indicators as proposed by TEEB (2010), the ES supply per land-use type was quantified in a two-step process. In our case, we refer to ES supply as the potential supply provided by ecosystems based on their functioning (van Oudenhoven et al., 2012). In contrast, we did not quantify the actual supply (or flow) of an ES, defined as the amount of the ES used by humans (Vallecillo et al., 2019). Since ecosystem processes, functions and structures commonly determine ES supply in a complex and multi-layered way, several measures need to be identified for the quantification of ES supply. Such measures can typically be divided into direct and indirect or supporting measures (Feld et al., 2010; Corstanje

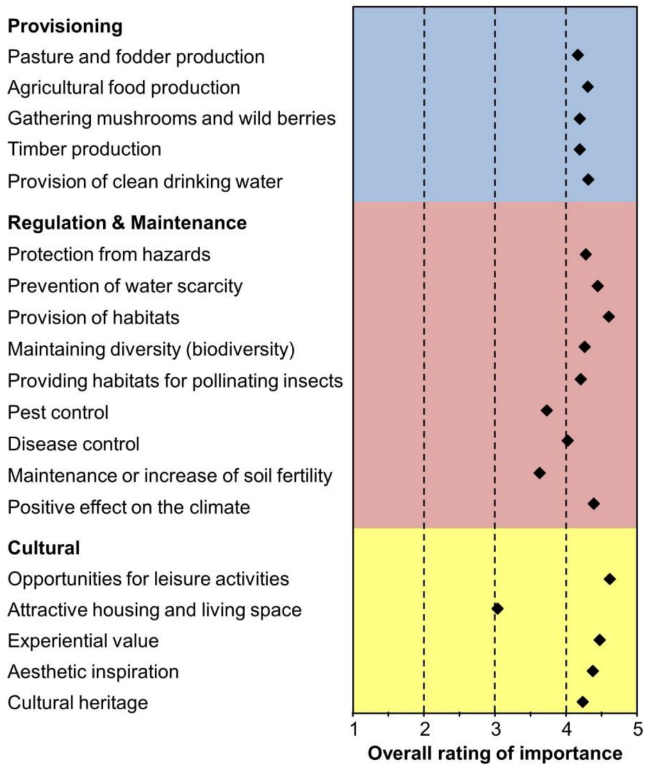

Fig. 3. Socio-cultural values of the most relevant ES in the study area (mean). Results were derived from two surveys conducted with a total number of 1458 local inhabitants. Values range from 1 (not important) to 5 (very important). Standard errors, ranging between 0.016 and −0.030, are very low and are thus not displayed.

et al., 2017). Whereas a direct measure refers directly to a certain ES, such as grassland production for forage production, an indirect measure delimits important boundary conditions for the provision of a service, such as sufficient nutrients and water for crop production. Most measures can be considered indirect measures for multiple ES. For instance, acidification of the soil can lead to lower soil fertility, and also to a reduction in soil stability. In the first step, ecosystem and landscape measures determining ES supply were collected based on a systematic literature review and subsequently assigned to the individual ES to serve as indicators for ES supply. By evaluating the literature, we collected a wide-range of measures potentially impacting ES supply in a direct or indirect way. Overall, we considered more than 50 data sources predominantly derived from *Web of Science* and *Google* in the case of local reports. Concretely, we looked for articles without any time restrictions using the search string ((Alps OR Alpine) AND ("measure*", see Table 1) AND ("land-use type*")). We selected all studies specifically carried out in the Central Alps. These provide quantitative data about a range of measures and for which data was available for all seven land-use types within the study region or a comparable European mountain or mountain foothill area. In some cases, reports and project reports (mostly in German or Italian) presenting results from various research institutes were additionally consulted. When selecting the literature, attention was paid to the consistency of the studies (methods, conditions) and to the verification of the data across several independent data sources as far as possible. This led to the consideration of a diverse range of data sources reporting quantitative data about different measures for all land-use types, including field observations, monitoring programmes, remote sensing applications or earth observations.

For various ES, however, not only the individual land-use type plays a decisive role, but also the diversity of the occurring ecosystems and the landscape structure in which the area is integrated (see e.g. Rusch et al., 2016, Rega et al., 2018, Bartual et al., 2019). This consideration holds true, for instance, for diversity in general but also for pollination and pest control. The same consideration applies to most cultural ES provided by landscapes (see e.g. Bastian et al., 2014; Schirpke et al., 2013, 2018a, 2018b; Westerink et al., 2017; Zoderer et al., 2016b). Therefore, we additionally included measures of landscape structure to quantify their impact on ES supply. To achieve this, landscape metrics were first calculated on the basis of defined ecoregions which are uniform landscape units arising from the interaction of site conditions (biotic and abiotic), agricultural and silvicultural use as well as settlement development (Tasser et al., 2009). The obtained results were subsequently assigned to the individual land-use types depending on their main distribution across these uniform landscape units. Furthermore, we also specifically considered landscape structure in the context of cultural ES. Therefore, we reviewed the literature for studies specifically dealing with cultural ES and which provide data about people's perceptions of the landscape's potential to provide cultural ES through surveys (Table 1). Cultural ES typically arise from the tight interaction between the biophysical characteristics of landscapes, their configuration and people's perception (Antrop, 2000; Gobster et al., 2007). The subjectivity and normativity of cultural ES, however, pose considerable challenges to their quantification (Daniel et al., 2012; Riechers et al., 2017). In contrast to other services, the quantification of the supply of cultural ES requires the consideration of both the biophysical features of landscapes and how they are perceived by people depending on their cultural, social and personal background (Zoderer et al., 2016a; Scholte et al., 2018). In this regard, public surveys can be used as an additional data source suitable for capturing people's perception of the supply of cultural ES in landscapes (Plieninger et al., 2013; van Zanten et al., 2016).

2.2.3. Quantification of ES supply indicators for land-use types

ES supply indicators were derived from the identified measures by assigning them to one or more ES. Based on the reviewed studies (see Table 1 for the main data sources) and expert knowledge, the relationship between the single measures and ES (i.e. positive or negative) was analysed. It was further determined whether each measure contributes to the provision of an ES in a direct or indirect way (see Table 2). All indicator values attributed to one specific ES were max-standardised across the seven land-use types to ensure that the impact of the single indicators is neither overemphasised nor underestimated when quantifying ES supply levels for each land-use type based on several indicators. In the case of a positive relationship between an indicator and ES supply (e.g. high forage production for the ES pasture and fodder production), the following formula was used to indicate that a land-use type with an indicator value of 1 represents the highest ES supply levels: $x_i^{'} = \frac{x_i}{\max(x)}$, where $x_i^{'}$ is the rescaled value per land-use type, $x_i$is the original value per land-use type and $\max(x)$ the maximum original value over all land-use types. In the case of a negative relationship between an indicator and ES (e.g. low phosphorus discharge for the ES provision of clean drinking water), the formula $x_i^{'} = 1 - \frac{(x_i - \min(x))}{\max(x)}$ was instead applied to indicate that a higher ES supply is reached when the indicator value is low. Finally, mean values were calculated over all standardised indicator values to estimate the provision supply of ES within each land-use type, taking into account that indicators can either serve as direct (weight of 1) or indirect indicators (weight of 0.2). The weighting values used are based on subjective estimations by the authors, aiming to quantitatively consider the stronger influence of direct indicators on the quantification of ES supply in comparison to indirect indicators.

2.2.4. Quantification of ES demand

ES demand was determined based on the results from two previously published empirical studies (Pecher et al., 2017; Zoderer et al., 2019a). In both studies, a questionnaire survey was carried out to capture people's expressed socio-cultural values towards ES, a

Table 1

Important ecosystem and landscape measures available for all land-use types considered. Values either represent individual or averaged values (in the case of several sources) derived from the literature, whereby only data sources generated within the study area or within a comparable European mountain or mountain foothill area were considered. Information on the measure type (FM = field measurement, TB = trait based values, MO = modelling output, SD = statistical data, PS = public survey) and the data sources are provided in the last columns.

No	Ecosystem and landscape attributes	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest	Measure type	Source
	Soil									
1	Rooting density (m m^{-2})	21.4	15.9	36.1	61.0	60.4	44.3	46.4	FM	1, 2
2	Rooting depth (cm)	9.3	18.4	12.7	21.8	20.1	28.2	43.5	FM	1, 2
3	N-content (%)	0.3	0.2	1.8	1.2	1.3	0.9	1.3	FM	3, 4, 5, 6
4	C-content (%)	3.38	3.2	9.6	10.1	12.2	14.8	12.9	FM	3, 4, 5, 7, 6
5	pH-value in the soil (pH)	6.8	6.5	5.3	4.6	4.6	4.5	3.5	FM	3, 4
6	Water conductivity (kF; mm h^{-1})	228.7	315.6	520.0	405.0	405.0	375.0	395.0	FM	8, 9, 10
7	Water retention capacity (%)	31.7	34.6	138.4	155.2	155.2	162.0	140.0	FM	8, 9, 10
	Microorganisms									
8	Bacterial biomass (mmol PLFA g^{-1} dry soil)	67	66.5	65.3	58.4	58.3	60.80	51.00	FM	11, 12, 13, 14
9	Fungal biomass (mmol PLFA g^{-1} dry soil)	3.3	3.1	3.8	7.0	7.0	7.8	11.5	FM	11, 12, 13, 14
10	Good and very good edible mushrooms (n species)	7	4	14	18	16	19	85	TB	58
11	Total phospholipid fatty acid, PLFA total (nmol g^{-1} dry soil)	53	63.0	60.0	95.0	95.0	118.0	110.0	FM	11, 12, 13, 14
	Flora									
12	Mean species richness of vascular plants (n)	17	20	25	34	33	28	27	FM	15, 16
13	Absolute species richness of vascular plants (n)	150	215	242	560	560	173	441	FM	15, 16
14	Endangered plant species (n)	12	63	12	37	145	79	55	FM	17
15	Species with edible berries (presence in %)	0	0	3.6	24.1	13.7	44.6	71.4	FM	15
16	Carbon stock (t ha^{-1})	25.4	9.7	13.0	11.2	13.6	18.1	104.0	FM	21
	Fauna									
17	Primary consumers – Orthoptera species (n)	3.3	9.2	8.0	8.7	6.0	7.7	4.0	FM	23, 24, 25
18	Secondary consumers – Coleoptera species (n)	11.33	9.50	18.00	16.67	17.00	16.00	10.50	FM	23, 26, 27
19	Diurnal butterfly species (n)	4.25	3.68	23.8	37.4	27.1	35.4	10.5	FM	28, 29, 30, 24
20	Wild bee species (n)	4.23	5.75	20	36	34	22	42	FM	31, 32, 33
21	Parasitizing wild bee species (n)	3.9	0.9	3	5	5	2	6	FM	31, 34
22	Diversity of soil macro fauna (BSQ)	138	97	128	131	95	115	161	FM	35
23	Biomass of soil macro fauna (g m^{-2})	6321	2553	5638	3211	2438	2975	2962	FM	35
	Ecosystem/agricultural production									
24	Feed digestibility (%)			64	59	59	53	49	TB	18
25	Palatability (index)			0.7	1	1	0.7	0.5	TB	18
26	Forage production (dt ha^{-1})	0.0	0.0	51.2	33.8	19.2	11.3	5.2	MO	19
27	Agricultural grassland yield (%)	0	0	100	50	18.4	0	0	MO	19, 20
28	Energy content of fodder (MJ NEL)	6	6.2	6	5.5	4.1	4.2	4	FM, TB	19, 20
29	Annual and permanent crop yield (working hours)	2981	1307	0	0	0	0	0	SD	21
30	Annual crop production (kg ha^{-1}, area weighted)	0	12297.4	0	0	0	0	0	FM	21
31	Permanent crop production (kg ha^{-1}, area weighted)	41705.7	0	0	0	0	0	0	FM	21
	Forest quality									
32	Tree density (n ha^{-1})	2400	0	15	242	273	1111	2352	FM	36
33	Solid wood mass (t ha^{-1})	58.0	0.0	0.0	4.7	5.3	21.5	346.0	FM, TB	36, 61
34	Vitality of young trees (%)	0	0	0	100	40	100	100	FM	36
35	Germination density of trees seedlings (n ha^{-1})	29	0	29	317	645	795	1096	FM	36
	Water quality									
36	Nitrate in the seepage water (NO_3; mg l^{-1})	67.3	110.5	52.7	19.0	8.0	0.0	30.8	FM	37, 38
37	Phosphorus discharge (kg P ha^{-1} a^{-1})	0.67	2.08	0.14	0.08	0.18	0.03	0.04	FM	39, 41, 42, 40
38	Total coliforms (CFU 100 ml^{-1})	35.5	12	35.5	5.6	19.3	6	4	FM	43
39	Critical Loads (kg N ha^{-1} a^{-1})	25	35	25	15	20	20	10	FM	44

(*continued on next page*)

Table 1 (*continued*)

No	Ecosystem and landscape attributes	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest	Measure type	Source
	Regional water supply									
40	Evapotranspiration (mm a^{-1})	1019	450	510	380	380	410	900	FM, MO	45, 46, 47
41	Infiltration (% of precipitation)	47	49	47	50	50	50	50	FM	47, 48
42	Surface discharge (% of precipitation)	7	24	0.72	0.92	0.92	0.96	0.48	FM	45, 49, 50
	Potential risks									
43	Potential risks for landslides (%)	0.15	0.45	0.28	0.07	0.28	0.45	0.02	MO	52, 51
44	Surface erosion (g dry weight m^{-2} $month^{-1}$)	2.12	26.47	0.88	0.54	0.54	1.35	0.76	FM, MO	53, 48, 52
45	Snow gliding distance (mm a^{-1})	20	90	90	185	100	310	20	MO	54
	Landscape structure									
46	Feature characteristic (Mean Patch S (MPS); n km^{-2})	4.36	3.84	6.79	5.37	4.59	5.00	3.84	FM	21, 63, 64
47	Complexity (Mean Perimeter-Area Ratio (MPAR); ratio)	0.041	0.039	0.037	0.034	0.033	0.036	0.040	FM	21, 63, 64
48	Heterogeneity (Mean Patch Edge (MPE); m)	3112.0	2779.7	2632.8	2726.7	3004.4	2571.8	2559.7	FM	21, 63, 64
49	Diversity (Shannon‘s Diversity Index (SHDI); index)	1.56	2.04	2.10	2.92	2.73	2.56	2.38	FM	21, 63, 64
50	Uniformity (Dominance (DI); index)	1.44	1.84	1.80	1.23	1.26	1.55	1.83	FM	21, 63, 64
	Landscape quality									
51	Ecosystem diversity (n sociological plant communities)	3	6	8	17	41	24	25	FM	15, 16
52	Naturalness (index)	4	3	4	5	5	5	6	TB	22
53	Opportunity for leisure activities (agreement in %)	2.5	3.6	4.6	5.5	4.6	4.1	4.7	PS	57
54	Aesthetic beauty (agreement in %)	3.2	4.1	5.1	5.9	4.2	4.1	5.1	PS	55, 56, 57, 62
55	Spirituality (agreement in %)	1.3	2.2	3.2	3.7	2.5	2.6	3.3	PS	57
56	Cultural heritage (agreement in %)	4.2	3.7	3.1	3.9	3.2	2.9	3.1	PS	57
57	Symbolic plants and animals (index)	0.23	0.19	0.24	0.19	0.31	0.34	0.24	PS, MO	59
58	Photo density (n ha^{-1})	0.09	0.09	0.14	0.18	0.08	0.06	0.04	FM	60

1: Tasser and Tappeiner (2005), 2: Tasser et al. (in preparation), 3: Gamper et al. (2007), 4: Gamper and Tasser (2002), 5: Capriel and Seiffert (2009), 6: www.monalisa-project.eu/, 7: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, , 2009), 8: Dietl (1998), 9: Hartmann et al. (2009), 10: Grashey-Jansen (2007), 11: Bardgett and McAlister (1999), 12: Zeller et al. (2001), 13: Fritze et al. (2000), 14: García-Orenes et al. (2013), 15: Lüth et al. (2011), 16: Tasser et al. (2007), 17: Wilhalm and Hilpold (2006), 18: Kasal and Dellagiacoma (1996), 19: Tasser et al. (2012), 20: Egger et al. (2004), 21: Egarter Vigl et al. (2017), 22: Rüdisser et al. (2012), 23: Bonavita et al. (1999), 24: Pascher et al. (2010), 25: Brown and Schmitt (2001), 26: Letardi et al. (2015), 27: Batáry et al. (2012), 28: Huemer and Tarmann (2001), 29: Huemer (2012), 30: Huemer (2004), 31: Kopf (2008), 32: Research Institute of Organic Agriculture (FiBL) (Research Institute of Organic Agriculture (FiBL), 2014), 33: Marini et al. (2012), 34: Steffan-Dewenter and Tscharntke (2001), 35: Rüdisser et al. (2015), 36: Tasser et al. (2002), 37: Hark et al. (1999), 38: Kolbe (2002), 39: Land Oberösterreich (2005), 40: Schütz et al. (2006), 41: Kubiniok (2009), 42: Halbfaß et al. (2009), 43: Gotkowska-Płachta et al. (2016), 44: Bayerisches Landesamt für Umwelt (LfU) (Landesamt and für Umwelt (LfU), 2004), 45: Bou-Vinals (2005), 46: Braun (2007), 47: Fritsch et al. (2011), 48: Zethner et al. (2015), 49: Leitinger et al. (2010), 50: Landesanstalt für Pflanzenbau (2002), 51: Beguería (2006), 52: Tasser et al. (2003), 53: Tasser et al. (1999), 54: Newesely et al. (2000), 55: Timmermann (2012), 56: Schirpke et al. (2013), 57: Zoderer et al. (2016b), 58: Garnweidner (1984), 59: Schirpke et al. (2018a), 60: Schirpke et al. (2018b), 61: Patek (2013), 62: Schirpke et al. (2016), 63: Tasser et al. (2009), 64: own calculation based on data from 21 and 63.

Table 2
Assignment of the indicators to individual ES, their underlying measures (see Table 1 for numbering), max-standardised values per land-use type, and mean weighted value per ES (in bold). The weighting factor of the individual indicators is given in brackets: direct indicator (weighting factor 1), indirect indicator (weighting factor 0.2). The attribution of measures to the single ES is based on a literature review and expert knowledge.

Classification after CICES V5.1 (January 2018)	Ecosystem service supply (in bold) and assigned indicators	Underlying measure (no see Table 1)	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest
Provisioning (Biotic); Biomass, Cultivated terrestrial plants for nutrition, materials or energy	**Pasture and fodder production**		**0.21**	**0.21**	**0.97**	**0.66**	**0.41**	**0.25**	**0.19**
	High forage production (1)	26	0.00	0.00	1.00	0.66	0.38	0.22	0.10
	High agricultural grassland yield (1)	27	0.00	0.00	1.00	0.50	0.18	0.00	0.00
	High energy content of fodder (0.2)	28	0.97	1.00	0.97	0.89	0.66	0.68	0.65
	High food palatability (0.2)	25	0.70	0.70	0.70	1.00	1.00	0.70	0.50
	High food digestibility (0.2)	24	1.00	1.00	1.00	0.92	0.92	0.83	0.77
	Agricultural food production		**0.67**	**0.48**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	High financial yield of crop production (1)	29	1.00	0.44	0.00	0.00	0.00	0.00	0.00
	High annual crop production (1)	30	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	High permanent crop production (1)	31	1.00	0.00	0.00	0.00	0.00	0.00	0.00
	Timber production		**0.52**	**0.00**	**0.01**	**0.17**	**0.15**	**0.40**	**1.00**
	High tree density (1)	32	1.00	0.00	0.01	0.10	0.11	0.46	0.98
	High solid wood mass (1)	33	0.14	0.00	0.00	0.01	0.02	0.06	1.00
	High vitality of young trees (0.2)	34	0.00	0.00	0.00	1.00	0.40	1.00	1.00
	High germination density of trees seedlings (0.2)	35	0.03	0.00	0.03	0.29	0.59	0.73	1.00
Provisioning (Biotic); Biomass, Wild plants (terrestrial and aquatic) for nutrition, materials or energy	**Gathering mushrooms and wild berries**		**0.04**	**0.02**	**0.11**	**0.27**	**0.19**	**0.42**	**1.00**
	High frequency of edible mushrooms (1)	10	0.08	0.05	0.16	0.21	0.19	0.22	1.00
	High frequency of wild berries (1)	15	0.00	0.00	0.05	0.34	0.19	0.63	1.00
Provisioning (Abiotic); Water, Ground water used for nutrition, materials or energy	**Provision of clean drinking water**		**0.40**	**0.26**	**0.53**	**0.92**	**0.81**	**0.98**	**0.91**
	Low nitrate in the seepage water (1)	36	0.39	0.00	0.52	0.83	0.93	1.00	0.72
	Low phosphorus discharge (1)	37	0.70	0.00	0.95	0.98	0.93	1.00	1.00
	Low total coliform concentration (1)	38	0.11	0.77	0.11	0.95	0.57	0.94	1.00
Regulation & Maintenance (Biotic); Regulation of physical, chemical, biological conditions, Regulation of baseline flows and extreme events	**Protection from hazards**		**0.69**	**0.30**	**0.73**	**0.81**	**0.77**	**0.54**	**0.94**
	High rooting density (0.2)	1	0.35	0.26	0.59	1.00	0.99	0.73	0.76
	High rooting depth (0.2)	2	0.21	0.42	0.29	0.50	0.46	0.65	1.00
	Low soil acidification (pH) (0.2)	5	1.00	0.96	0.78	0.68	0.68	0.66	0.51
	High water retention capacity (0.2)	7	0.20	0.21	0.85	0.96	0.96	1.00	0.86
	Low potential risks for landslides (1)	43	0.71	0.04	0.42	0.87	0.42	0.04	1.00
	Low surface erosion (1)	44	0.94	0.02	0.99	1.00	1.00	0.97	0.99
	Low snow gliding distance (1)	45	1.00	0.77	0.77	0.47	0.74	0.06	1.00
	Prevention of water scarcity		**0.55**	**0.54**	**0.92**	**0.98**	**0.98**	**0.97**	**0.83**
	Low evapotranspiration (1)	40	0.37	0.93	0.87	1.00	1.00	0.97	0.49
	Low surface discharge (0.2)	42	0.73	0.02	0.99	0.98	0.98	0.98	1.00
	High infiltration capacity (1)	41	0.94	0.98	0.94	1.00	1.00	1.00	1.00
	High water retention capacity(1)	7	0.20	0.21	0.85	0.96	0.96	1.00	0.86
	High water conductivity (0.2)	6	0.44	0.61	1.00	0.78	0.78	0.72	0.76

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Table 2 (*continued*)

Classification after CICES V5.1 (January 2018)	Ecosystem service supply (in bold) and assigned indicators	Underlying measure (no see Table 1)	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest
Regulation & Maintenance (Biotic); Regulation of physical, chemical, biological conditions, Lifecycle maintenance, habitat and gene pool protection	**Provision of habitats**		**0.43**	**0.38**	**0.48**	**0.69**	**0.92**	**0.73**	**0.79**
	High ecosystem diversity (1)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	High naturalness (1)	52	0.67	0.50	0.67	0.83	0.83	0.83	1.00
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (0.2)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67
	Maintaining biodiversity		**0.40**	**0.46**	**0.50**	**0.72**	**0.88**	**0.64**	**0.71**
	High ecosystem diversity (1)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	High naturalness (0.2)	52	0.67	0.50	0.67	0.83	0.83	0.83	1.00
	High mean species richness of vascular plants (0.2)	12	0.51	0.59	0.75	1.00	0.98	0.82	0.79
	High absolute species richness of vascular plants (1)	13	0.27	0.38	0.43	1.00	1.00	0.31	0.79
	Many endangered plant species (1)	14	0.08	0.43	0.08	0.26	1.00	0.54	0.38
	High bacterial biomass (0.2)	8	1.00	0.99	0.97	0.87	0.87	0.91	0.76
	High fungal biomass (0.2)	9	0.29	0.27	0.33	0.61	0.61	0.68	1.00
	High diversity in soil macro fauna (1)	11	0.86	0.60	0.80	0.81	0.59	0.72	1.00
	High diversity of primary consumers (0.2)	17	0.36	1.00	0.87	0.95	0.65	0.84	0.44
	High diversity of secondary consumers (0.2)	18	0.63	0.53	1.00	0.93	0.94	0.89	0.58
	High diversity of wild bee species (0.2)	20	0.10	0.14	0.48	0.86	0.82	0.54	1.00
	High diversity of diurnal butterfly species (0.2)	19	0.11	0.10	0.63	1.00	0.72	0.95	0.28
	High landscape heterogeneity (0.2)	48	1.00	0.89	0.85	0.88	0.97	0.83	0.82
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (0.2)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67
	Providing habitats for pollinating insects		**0.33**	**0.33**	**0.59**	**0.89**	**0.84**	**0.76**	**0.71**
	High diversity of diurnal butterfly species (1)	19	0.11	0.10	0.63	1.00	0.72	0.95	0.28
	High diversity of wild bee species (1)	20	0.10	0.14	0.48	0.86	0.82	0.54	1.00
	High ecosystem diversity (0.2)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	High mean species richness of vascular plants (0.2)	12	0.51	0.59	0.75	1.00	0.98	0.82	0.79
	High landscape heterogeneity (0.2)	48	1.00	0.89	0.85	0.88	0.97	0.83	0.82
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (0.2)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67
	Low patch size (0.2)	46	0.92	1.00	0.57	0.77	0.89	0.83	1.00
	High naturalness (0.2)	52	0.67	0.50	0.67	0.83	0.83	0.83	1.00

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Table 2 (*continued*)

Classification after CICES V5.1 (January 2018)	Ecosystem service supply (in bold) and assigned indicators	Underlying measure (no see Table 1)	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest
Regulation & Maintenance (Biotic); Regulation of physical, chemical, biological conditions, Pest and disease control	**Pest control**		**0.73**	**0.51**	**0.75**	**0.85**	**0.82**	**0.70**	**0.86**
	High diversity of soil macro fauna (1)	22	0.86	0.60	0.80	0.81	0.59	0.72	1.00
	High diversity of parasitizing wild bee species (1)	21	0.63	0.14	0.49	0.76	0.84	0.37	1.00
	High diversity of secondary consumers (1)	18	0.63	0.53	1.00	0.93	0.94	0.89	0.58
	High landscape heterogeneity (0.2)	48	1.00	0.89	0.85	0.88	0.97	0.83	0.82
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (0.2)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67
	Low patch size (0.2)	46	0.92	1.00	0.57	0.77	0.89	0.83	1.00
	High naturalness (1)	52	0.67	0.50	0.67	0.83	0.83	0.83	1.00
	Disease control		**0.69**	**0.60**	**0.78**	**0.86**	**0.76**	**0.73**	**0.81**
	High diversity of soil macro fauna (1)	22	0.86	0.60	0.80	0.81	0.59	0.72	1.00
	High diversity of primary consumers (1)	17	0.36	1.00	0.87	0.95	0.65	0.84	0.44
	High diversity of secondary consumers (1)	18	0.63	0.53	1.00	0.93	0.94	0.89	0.58
	High diversity of parasitizing wild bee species (1)	21	0.63	0.14	0.49	0.76	0.84	0.37	1.00
	High biomass of soil macro fauna (1)	23	1.00	0.40	0.89	0.51	0.39	0.47	0.47
	High landscape heterogeneity (0.2)	48	1.00	0.89	0.85	0.88	0.97	0.83	0.82
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (0.2)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67
	Low patch size (0.2)	46	0.92	1.00	0.57	0.77	0.89	0.83	1.00
	High naturalness (1)	52	0.67	0.50	0.67	0.83	0.83	0.83	1.00
Regulation & Maintenance (Biotic); Regulation of physical, chemical, biological conditions, Regulation of soil quality	**Maintenance or increase of soil fertility**		**0.63**	**0.54**	**0.76**	**0.65**	**0.65**	**0.71**	**0.68**
	High total N-content in the soil (1)	3	0.16	0.10	1.00	0.65	0.72	0.53	0.71
	High total C-content in the soil (1)	4	0.23	0.22	0.65	0.68	0.82	1.00	0.87
	Low soil acidification (pH) (1)	5	1.00	0.96	0.78	0.68	0.68	0.66	0.51
	High total phospholipid fatty acid (PLFA total) (1)	11	0.45	0.53	0.51	0.81	0.81	1.00	0.93
	High diversity of soil macrofauna (1)	22	0.86	0.60	0.80	0.81	0.59	0.72	1.00
	High biomass of soil macrofauna (1)	23	1.00	0.40	0.89	0.51	0.39	0.47	0.47
	High Critical Loads (1)	39	0.71	1.00	0.71	0.43	0.57	0.57	0.29
Regulation & Maintenance (Biotic); Regulation of physical, chemical, biological conditions, Atmospheric composition and conditions	**Positive effect on the climate**		**0.54**	**0.29**	**0.48**	**0.50**	**0.54**	**0.61**	**0.94**
	High evapotranspiration (1)	40	1.00	0.40	0.50	0.37	0.37	0.40	0.88
	High total C-content in the soil (1)	4	0.23	0.22	0.65	0.68	0.82	1.00	0.87
	High carbon stock (1)	16	0.24	0.09	0.13	0.11	0.13	0.17	1.00
	High naturalness (1)	52	0.67	0.50	0.67	0.83	0.83	0.83	1.00
	High water retention capacity (0.2)	7	0.20	0.21	0.85	0.96	0.96	1.00	0.86
	High tree density (0.2)	32	1.00	0.00	0.01	0.10	0.11	0.46	0.98

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Table 2 (*continued*)

Classification after CICES V5.1 (January 2018)	Ecosystem service supply (in bold) and assigned indicators	Underlying measure (no see Table 1)	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest
Cultural (Biotic); Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting, Physical and experiential interactions with natural environment	**Opportunities for leisure activities**		**0.53**	**0.62**	**0.78**	**1.00**	**0.98**	**0.78**	**0.78**
	Many opportunities for leisure activities (1)	53	0.45	0.64	0.83	1.00	0.84	0.75	0.84
	High aesthetic beauty (0.2)	55	0.57	0.72	0.80	1.00	0.82	0.82	0.85
	High ecosystem diversity (1)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	High landscape complexity (0.2)	47	1.00	0.96	0.92	0.84	0.80	0.89	0.99
	High landscape diversity (0.2)	48	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	High landscape uniformity (0.2)	50	0.79	1.00	0.98	0.67	0.68	0.85	1.00
	High visitor frequency (1)	58	0.47	0.50	0.74	1.00	0.43	0.36	0.04
Cultural (Biotic); Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting, Intellectual and representative interactions with natural environment	**Attractive housing and living space**		**0.44**	**0.76**	**0.84**	**0.90**	**0.82**	**0.71**	**0.63**
	High ecosystem diversity (0.2)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	Low tree density (1)	32	0.00	1.00	0.99	0.90	0.89	0.54	0.02
	Many opportunities for leisure activities (1)	53	0.45	0.64	0.83	1.00	0.84	0.75	0.84
	High aesthetic beauty (1)	54	0.57	0.72	0.80	1.00	0.82	0.82	0.85
	High spirituality (0.2)	55	0.34	0.59	0.85	1.00	0.66	0.68	0.88
	High cultural heritage (0.2)	56	1.00	0.86	0.73	0.92	0.76	0.67	0.72
	Low landscape complexity (0.2)	47	0.80	0.84	0.88	0.96	1.00	0.92	0.82
	Low landscape diversity (0.2)	49	1.00	0.84	0.81	0.53	0.60	0.66	0.72
	High landscape uniformity (0.2)	50	0.79	1.00	0.98	0.67	0.68	0.85	1.00
	High patch size (0.2)	46	0.64	0.57	1.00	0.79	0.68	0.74	0.57
	Experiential value		**0.35**	**0.37**	**0.48**	**0.71**	**0.73**	**0.71**	**0.73**
	High ecosystem diversity (1)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	High mean species richness of vascular plants (1)	12	0.51	0.59	0.75	1.00	0.98	0.82	0.79
	Many endangered plant species (0.2)	14	0.08	0.43	0.08	0.26	1.00	0.54	0.38
	High diversity in soil macro fauna (0.2)	22	0.86	0.60	0.80	0.81	0.59	0.72	1.00
	High diversity of primary consumers (0.2)	17	0.36	1.00	0.87	0.95	0.65	0.84	0.44
	High diversity of secondary consumers (0.2)	18	0.63	0.53	1.00	0.93	0.94	0.89	0.58
	High diversity of diurnal butterfly species (1)	19	0.11	0.10	0.63	1.00	0.72	0.95	0.28
	Frequency of edible mushrooms (1)	10	0.08	0.05	0.16	0.21	0.19	0.22	1.00
	Frequency of wild berries (1)	15	0.00	0.00	0.05	0.34	0.19	0.63	1.00
	High landscape diversity (1)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (1)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67
	Low patch size (0.2)	46	0.92	1.00	0.57	0.77	0.89	0.83	1.00
	Aesthetic inspiration		**0.48**	**0.60**	**0.69**	**0.87**	**0.80**	**0.72**	**0.75**
	High ecosystem diversity (0.2)	51	0.07	0.15	0.20	0.41	1.00	0.59	0.61
	High aesthetic beauty (1)	54	0.57	0.72	0.80	1.00	0.82	0.82	0.85
	High spirituality (0.2)	55	0.34	0.59	0.85	1.00	0.66	0.68	0.88
	Low landscape complexity (0.2)	47	0.80	0.84	0.88	0.96	1.00	0.92	0.82
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	High landscape uniformity (0.2)	50	0.79	1.00	0.98	0.67	0.68	0.85	1.00

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Table 2 (*continued*)

Classification after CICES V5.1 (January 2018)	Ecosystem service supply (in bold) and assigned indicators	Underlying measure (no see Table 1)	Permanent culture	Arable land	Fertilised hay meadows	Non-fertilised hay meadows	Low-intensity pasture	Abandoned land	Forest
	Cultural heritage		**0.55**	**0.60**	**0.77**	**0.79**	**0.78**	**0.83**	**0.78**
	High cultural importance (0.2)	56	1.00	0.86	0.73	0.92	0.76	0.67	0.72
	High spirituality (1)	55	0.34	0.59	0.85	1.00	0.66	0.68	0.88
	High abundance of symbolic plants and animals (1)	57	0.68	0.56	0.70	0.56	0.90	1.00	0.69
	High landscape diversity (0.2)	49	0.53	0.70	0.72	1.00	0.94	0.88	0.82
	Low landscape uniformity (0.2)	50	0.88	0.67	0.69	1.00	0.98	0.82	0.67

commonly accepted non-monetary measure of people's demand for ES (Villamagna et al., 2013; Wolff et al., 2015). The two studies differ regarding the number of key ES considered and the valuation technique employed. While in Pecher et al. (2017) 16 out of the 19 key ES were included, Zoderer et al. (2019a) covered 13 of these services. In Pecher et al. (2017), respondents were asked to assess the importance of ES for their personal well-being on a five-point Likert scale, ranging from one (low importance) to five (high importance). In Zoderer et al. (2019a), survey participants were asked to select a maximum number of five services from a total list of 15 ES that contribute most to their personal well-being. In order to standardise these different forms of assessment, the respective survey results were correlated via 10 overlapping ES and standardised using the resulting correlation function: $r^2 = 0.7026$, $p < 0.05$, $y = 0.0092x + 4.043$, where y is the standardised predicted socio-cultural value and x the socio-cultural value as derived from the survey in Zoderer et al. (2019a). The questionnaires were available in German and Italian, and took the respondents approximately 20 min to complete. For more details see Pecher et al. (2017) and Zoderer et al. (2019a).

During spring and summer 2010 and 2016, a total of 1458 face-to-face interviews were conducted with local inhabitants in Tyrol and South Tyrol. The sample of locals was representative of the population with respect to gender, age, urban-rural distribution and language groups (Italian and German in South Tyrol).

2.2.5. *Quantification of land-use type values*

To estimate the value of land-use types, the indicator-based estimations of ES supply were combined with the ES demand as derived from the questionnaire surveys. To achieve this, we first calculated the mean across ES supply for each land-use type (values range between 0 and 1). Subsequently we weighted this value with the socio-cultural value of ES (values range between 1 and 5), which corresponded to the valuation of the ES by the survey respondents on a five-point Likert scale. ES that were more preferred thus affected mean values of ES supply more, and ES of less interest to people influenced the means to a lesser extent. To calculate a land-use type value for each ES category (i.e. provisioning services, regulation & maintenance services, and cultural service), the individual weighted ES values were averaged per category. Finally, an *overall land-use type value* was calculated for the seven land-use types by averaging ES values of all three categories. To test for significant differences between the calculated mean values across ES categories as well as across land-use types, pairwise comparisons were conducted using Least Significant Difference (LSD) tests. Due to the small sample size (5–10 per ES category), the LSD tests were carried out at a significance level of $p < 0.10$. For illustrative purposes, we spatially displayed the estimated land-use type values according to the extent and spatial distribution of the land-use types within the study region. All calculations were performed using SPSS software package (version 24, IBM) and ArcMap (version 10.2.2, ESRI).

2.2.6. *Exploring similarities between land-use types regarding their ES supply–demand patterns*

We performed a principal component analysis (PCA) for the entire dataset to assess current similarities between land-use types (similarly to Maes et al., 2012, García-Nieto et al., 2013) in terms of their ES supply–demand patterns. Negative and positive associations between ES were analysed, taking both the supply and demand of ES into account. We defined a negative association as the simultaneous increase of one ES as a consequence of the reduction of another service (Rodríguez et al., 2006). Conversely, we defined a positive association when two ES are enhanced. The analyses project the data for each ES into a two-dimensional coordinate plane (components F1 and F2). The Kaiser criterion (i.e., eigenvalue > 1) was used to select the principal components that account for most of the variance of the measures. All the statistical analyses were performed using the Canoco 5.0 software package (http://www.canoco5.com).

3. Results

3.1. Key ES in the Alpine region and their socio-cultural values

Nineteen ES were identified as the most relevant for the Alpine region on the basis of interviews with experts and the general public, as well as a literature review (see Fig. 3). The list of key services comprised five provisioning (pasture and fodder production, agricultural food production, gathering mushrooms and wild berries, timber production, and provision of clean drinking water), nine regulation & maintenance (protection against erosion and flooding, prevention of water scarcity, provision of habitats for animals and plants, maintaining diversity, providing habitats for pollinating insects, pest control, disease control, maintenance or increase of soil fertility, and positive effect on the climate), and five cultural services (opportunities for leisure activities, attractive housing and living space, experiential value, aesthetic inspiration, and cultural heritage). The survey results clearly showed that all ES mentioned were considered moderately important to very important by local inhabitants (Fig. 3). The services that were considered by far the most important were the opportunities for leisure activities and provision of habitats for animals, followed by prevention of water scarcity, experiential value, positive effect on the climate, maintaining diversity (biodiversity), and protection against erosion and flooding. In contrast, the services that were regarded as least important by respondents included the provision of attractive housing and living space, and the maintenance or increase in soil fertility.

3.2. ES supply of different land-use types

Overall, we were able to identify 58 direct and indirect measures for the provision of ES, including seven soil-specific measures, 13 landscape-specific measures and seven faunistic measures (Table 1). Many of the measures identified also covered functional organism groups (microorganisms, fauna, flora), aspects of vegetation and canopy structure, water quality and quantity, erosion risk, and various cultural landscape attributes. Depending on the number of data sources identified, the values either represent individual values or averaged values for the different land-use types.

In the next step, these measures were translated into ES indicators by assigning them to the individual ES in a targeted manner on the basis of a literature review and expert knowledge. Whereas high indicator values support the individual ES, low values reduce them (Table 2). For example, an increase in root penetration promotes soil stability and reduces the erosion risk, and a high grassland yield promotes the ‘Pasture and fodder production’ ES. Overall, a minimum of two and a maximum of nine indicators were identified for each ES, while ensuring that data was available for all indicators across land-use types. Since all indicators attributed to one ES were first standardised and averaged per land-use type, final ES supply values range between 0 and 1. Permanent cultures (1.0) and arable land (0.44) showed the highest potential supply for ‘crops and fruits grown by humans for food’, whereas capacities to provide this service were lowest for all other land-use types. Extensively used hay meadows (0.88), abandoned land (0.94) and forests (0.86) in contrast, were characterised by particularly high potentials to provide clean drinking water, while the same service was only poorly fulfilled in arable land (0.22) and permanent cultures (0.36). A similar pattern was also found for other services, including the ‘maintaining diversity’ ES.

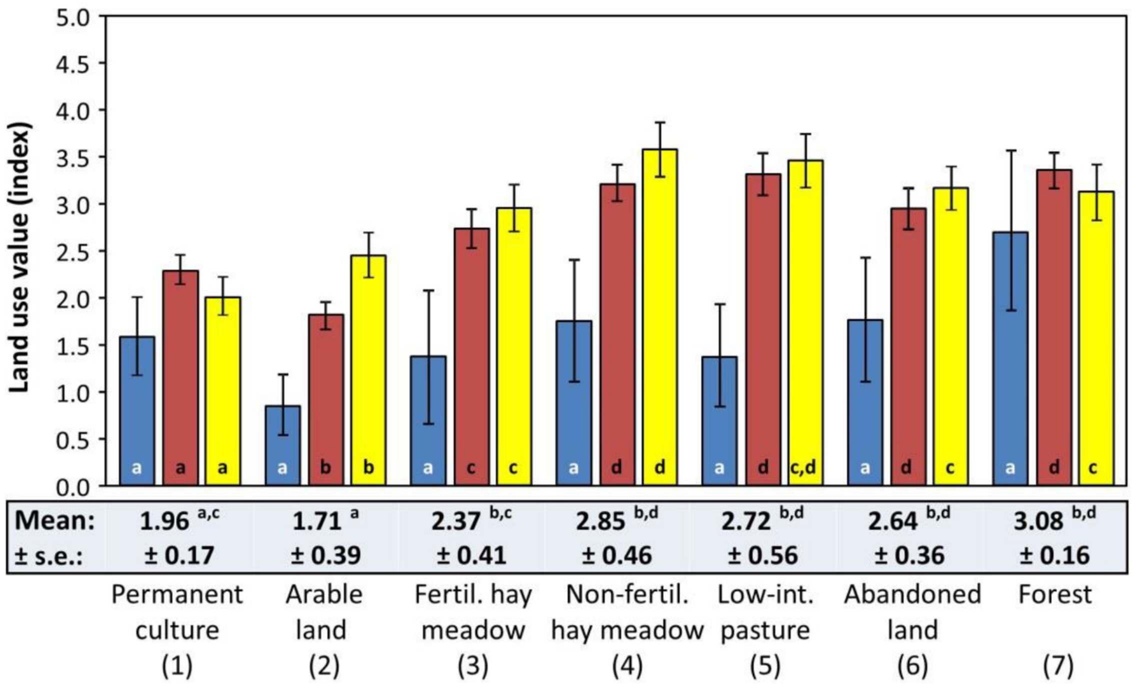
3.3. The value of land-use types

A comparison across ES categories demonstrates that all land-use types were characterised by lower values for those related to provisioning services than for the other two categories (Fig. 4). This is partly due to the slightly below-average rating of provisioning ES by respondents, but also due to the fact that the different land-use types provide completely different provisioning services – a finding that is also indicated by the large standard errors and the lack of significant differences between land-use types with regards to these services. Food and fodder are predominantly produced on agricultural land, and timber and various forest fruits grow mainly in forests. Overall, none of the investigated land-use types was attributed with high potentials to provide all provisioning services on an equally high level. In contrast, significant differences were found between intensively used land-use types (i.e. permanent cultures, arable land, fertilised hay meadows) and all other land-use types regarding the provision of regulation & maintenance ES. The same finding holds true for cultural ES. Overall land-use type values were found to be highest for forests, since this land-use type offers the largest number of services at a relatively high level, including those regarded as important by local inhabitants (e.g. prevention of water scarcity, positive effect on the climate). Extensively used hay meadows and pastures, in turn, reached particularly high values regarding regulation & maintenance and the cultural ES services category, because many of these services were important for respondents and were also provided on a high level (e.g. opportunities for leisure activities, provision of habitats). In particular, extensively used hay meadows and pastures are home to a large number of habitats and species, have a stabilising effect against erosion, increase the availability of usable water and are also aesthetically attractive and culturally valuable. The lowest average values, in contrast, were associated with arable land and permanent cultures. Both these land-use types are characterised by a lower supply of the ES important for local inhabitants.

We compared the results of our integrative approach with land-use type values estimated based on the supply of ES only (Fig. 5). The comparison demonstrates that the patterns of land-use type values identified by the two approaches are very similar overall, with a few exceptions however. While arable land appears to be valued lowest and forests to be valued highest regardless of whether the demand is considered in addition to the supply of ES, interesting differences emerge with regard to the valuation of non-fertilised hay meadows and low-intensity pastures. Although low-intensity pastures show a greater potential for the provision of ES, we found that non-fertilised hay meadows are of relative greater value when also considering the demand of local inhabitants for ES. Fig. 5 illustrates the theoretical range of land-use type values when considering the demand in addition to the supply of ES, indicating that the influence of demand can be highest (i.e. large range) for those land-use types that are characterised by great potential to provide multiple ES at a high level. Overall, our results show that the influence of ES demand on the land-use type values remains low overall in our study as respondents expressed a high demand for all ES (socio-cultural values range between 3.6 and 4.6).

3.4. The spatial distribution of land-use type values across the study site

The spatial distribution of land-use values revealed several hot- and cold-spot areas. Particularly low values were associated with the broad valley floors, where permanent cultures (Etsch/Adige Valley in South Tyrol) and arable land (Inn Valley in Tyrol) mainly dominate. Whereas these areas were characterised by relatively high values regarding several provisioning services, only a few cultural and regulation & maintenance services were provided in the same areas (compare Fig. 6a–c). In contrast, non-fertilised hay meadows, alpine pastures, and abandoned land located on higher elevations were regarded as particularly valuable for the provision of many cultural services important to local inhabitants (Fig. 6c). Large forest areas stretching along the valley slopes were particularly characterised by a high degree of provisioning services, but also regulation & maintenance and cultural services. As a result, these forest areas revealed the overall highest land-use value across all three ES categories (Fig. 6d).



Ecosystem service	1	2	3	4	5	6	7
Pasture and fodder production	0.85	0.86	4.04	2.75	1.72	1.06	0.77
Agricultural food production	2.86	2.06	0.00	0.00	0.00	0.00	0.00
Timber production	2.18	0.00	0.02	0.71	0.62	1.66	4.53
Gathering mushrooms and wild berries	0.17	0.10	0.45	1.15	0.79	1.77	4.18
Provision of clean drinking water	1.81	1.19	2.39	4.16	3.66	4.43	4.09
Protection from hazards	2.93	1.27	3.13	3.46	3.29	2.30	4.00
Prevention of water scarcity	2.46	2.40	4.09	4.34	4.34	4.34	3.72
Provision of habitats	1.97	1.77	2.20	3.17	4.26	3.38	3.67
Maintaining biodiversity	1.72	1.95	2.13	3.07	3.75	2.72	3.03
Providing habitats for pollinating insects	1.40	1.40	2.47	3.75	3.54	3.21	2.99
Pest control	2.72	1.88	2.78	3.17	3.07	2.62	3.21
Disease control	2.77	2.42	3.11	3.45	3.04	2.92	3.26
Maintenance or increase of soil fertility	2.29	1.98	2.77	2.37	2.38	2.57	2.48
Positive effect on the climate	2.37	1.29	2.11	2.20	2.37	2.69	4.11
Opportunities for leisure activities	2.34	2.83	3.58	4.59	4.52	3.56	3.60
Attractive housing and living space	1.35	2.30	2.56	2.73	2.49	2.16	1.91
Experiential value	1.54	1.65	2.15	3.18	3.24	3.16	3.26
Aesthetic inspiration	2.35	3.00	3.32	3.94	3.64	3.49	3.64
Cultural heritage	2.45	2.60	3.23	3.50	3.43	3.53	3.29

Provisioning services | Regulation & Maintenance services | Cultural services

Fig. 4. Mean land-use type values across ES categories (± s.e.), per ES category (above) and for individual ES (below) based on ES supply and ES demand. Pairwise comparison of means between the three ES categories and the overall land-use type values were performed using LSD (Least Significant Difference) test ($p < 0.10$). Significant mean differences between land-use types are indicated with different letters.

3.5. Similarities between land-use types

The similarities between land-use types regarding their ES supply–demand patterns were analysed using PCA. We reduced the 19 ES-variables to two dimensions, in which the first two components accounted for 85% of the total variance (Fig. 7). The variance in the data revealed a clear pattern of relationships between the ES of the seven land-use types. The first PCA axis (F1) was characterised by a positive correlation between agricultural food and fodder production, as well as cultural heritage values. Land-use types such as permanent cultures, arable land, and fertilised hay meadows, providing these services above average, were predominately allocated on this axis. All other land-use types were located on the same axis, in the opposite direction. These land-use types were particularly associated with the provision of clean drinking water, the provision of habitats for animals and plants, and of habitats for pollinating insects. The second axis of the PCA (F2)

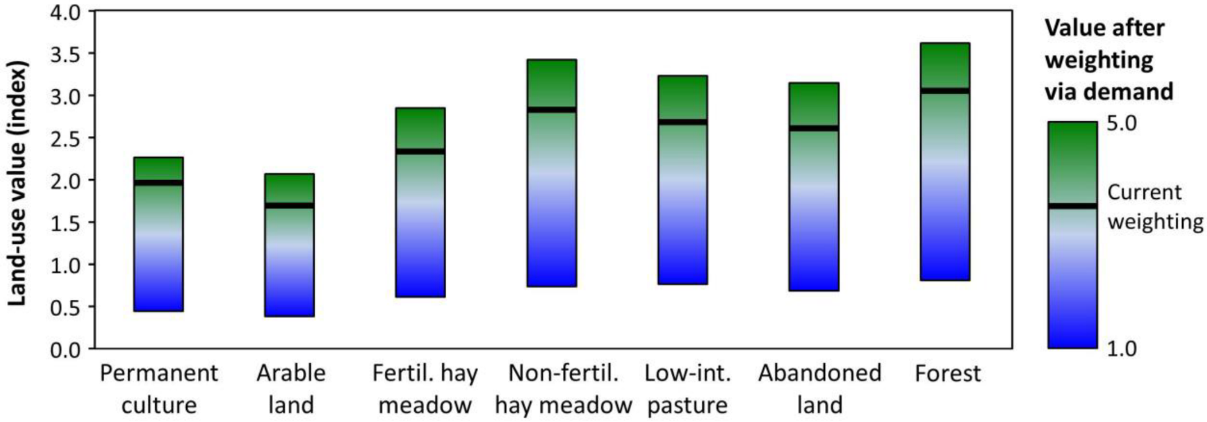


Fig. 5. Theoretical range of land-use type values when considering the demand for ES. The bold line (i.e. current weighting) indicates the land-use type value as estimated in this study by integrating both the supply and demand of multiple ES. The minimum value corresponds to the land-use type value without demand (supply only) or in the case that the supply is weighted by a minimum demand of 1. The maximum value corresponds to the land-use type value derived when weighting the supply with a maximum demand of 5.

separated forest and permanent cultures from pastures and hay meadows. Whereas forests and permanent cultures were predominantly associated with provisioning services like timber provision and the provision of wild food, pastures and hay meadows reached above-average values regarding the prevention of water scarcity, the maintenance of biodiversity, and the provision of opportunities for leisure activities.

4. Discussion

4.1. Strengths of the approach

Existing ES research aiming at producing policy-relevant information faced a trade-off between generating output that is up-to-date, easy to use and comprehensive on the one hand, and that is detailed and

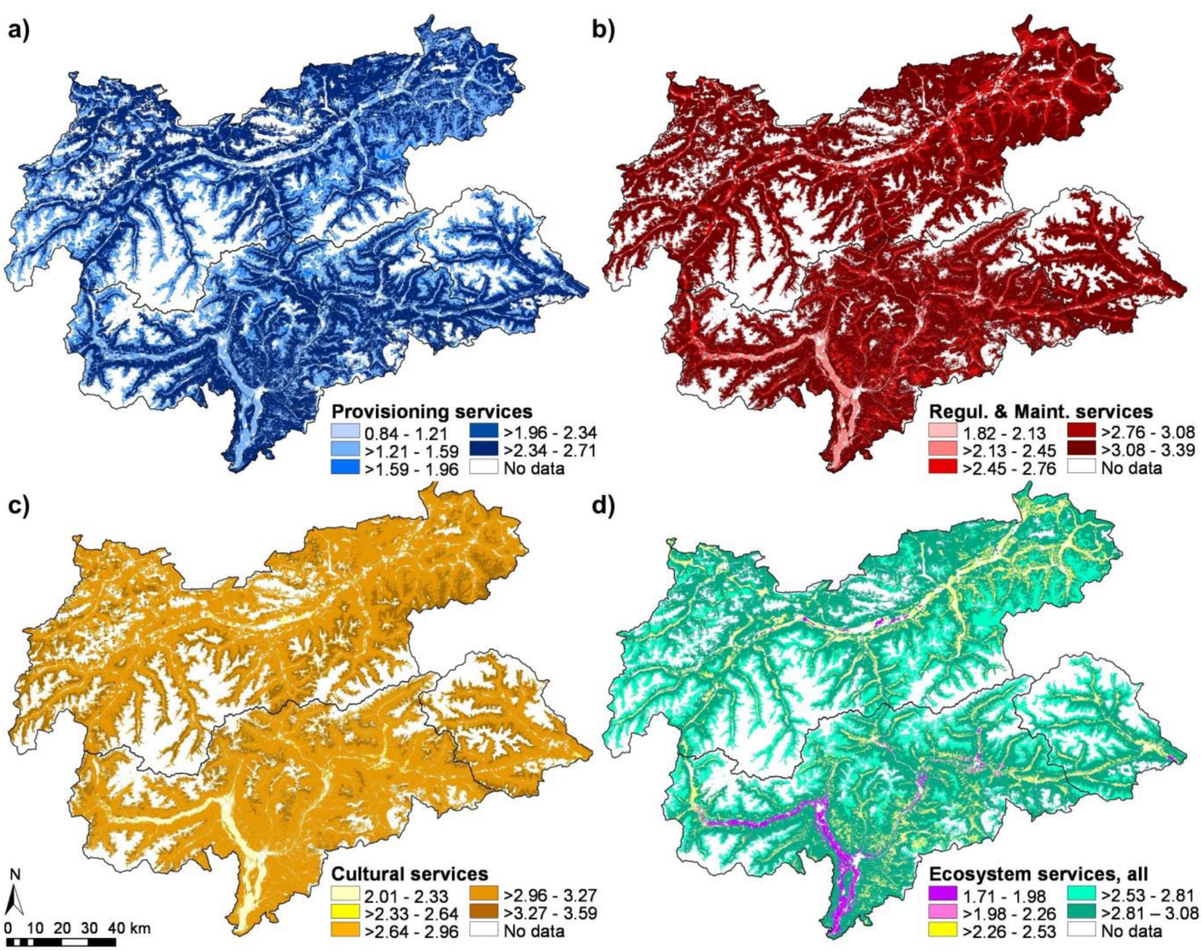


Fig. 6. Spatial distribution of the land-use type values (equal intervals) in Tyrol and South Tyrol regarding a) provisioning services, b) regulation & maintenance services, c) cultural services, and d) all ES (average of the three ES categories).

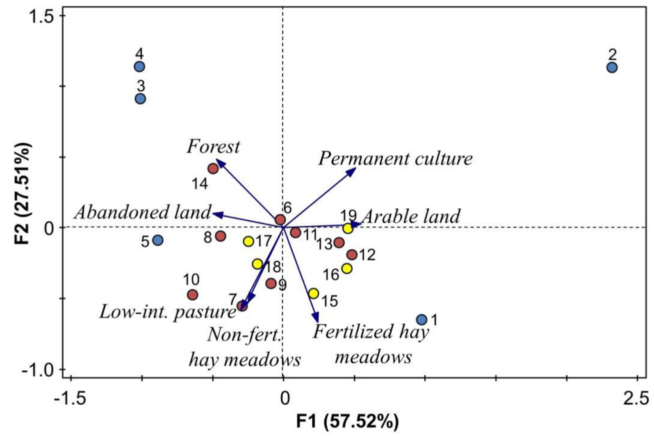


Fig. 7. Biplot of the principal component analysis (PCA) illustrating the negative and positive association between specific ES (coloured symbols for ES categories) and different land-use types (vectors). ES categories: provisioning services (blue symbols), regulation & maintenance (red), cultural services (yellow) ES: 1: Pasture & fodder production, 2: Agricultural food production, 3: Gathering mushrooms & wild berries, 4: Timber production, 5: Provision of clean drinking water, 6: Protection against erosion and flooding, 7: Prevention of water scarcity, 8: Provision of habitats for animals and plants, 9: Maintaining diversity (biodiversity), 10: Providing habitats for pollinating insects, 11: Pest control, 12: Disease control, 13: Maintenance or increase of soil fertility, 14: Positive effect on the climate, 15: Opportunities for leisure activities, 16: Attractive housing and living space, 17: Experiential value, 18: Aesthetic inspiration, 19: Cultural heritage.

scientifically robust on the other (Müller and Burkhard, 2012; Jacobs et al., 2015). The approach presented in this study addresses this 'science-policy dilemma' in a novel way by relying on existing secondary data, enabling an integrative assessment and comparison of multiple land-use types. In particular, we would like to highlight four strengths of this approach.

First, responding to calls for integrative assessments of land-use types (Agarwala et al., 2014; Dick et al., 2014; van Oudenhoven et al., 2018), our approach includes a wide spectrum of ES, specifically taking into account those considered relevant by experts and local inhabitants in the Alpine region. This enables the study of interactions between ES, which makes underlying synergies and trade-offs between services visible, both within and across land-use types. Previous research highlighted the importance of such information about interactions in spatial planning and land management (Cord et al., 2017; Costanza et al., 2017).

Second, and specifically compared to expert judgements (e.g. Burkhard et al., 2009; Haines-Young et al., 2012), our approach benefits from the use of quantitative measures from existing data sources, which allows for quantitative precision and the recognition of idiosyncratic characteristics of each ES. In particular, more reliable and accurate data are derived from actual field measurements, trait based data, modelling outputs, statistical analysis and public surveys, and their flexible combination specific to each ES type. This variation in methods is necessary to take more subjective and intangible ES into consideration, for which expert judgements are often inadequate (Daniel et al., 2012).

Third, our approach deviates from previous research which either focused solely on the supply side in quantifying ES (e.g. Haines-Young et al., 2012; Maes et al., 2016) or identified mismatches between supply and demand without integrating them into a single output (e.g. Burkhard et al., 2012; García-Nieto et al., 2013). Through integrating supply and demand, the final output reflects both the biophysical capacity of land-use types for the provision of ES as well as their socio-cultural value. This is in line with perspectives conceiving of land-use types as social-ecological systems, coupling both the natural and human factors as well as their related feedbacks (Angelstam et al., 2013; Fischer et al., 2015).

Fourth, we suggest that the approach outlined in this paper represents a flexible tool for producing outputs at different levels of aggregation, addressing the needs of policy-makers as discussed by Müller and Burkhard (2012). Depending on the specific needs, the value of land-use types can either be assessed at the level of individual ES, ES categories or entire land-use types. The advantage of such a hierarchical approach to aggregation lies in its ability to produce information that is highly compressed, while leaving open the possibility for stakeholders to gain deeper insights into single ES.

4.2. Methodological challenges

The method presented in this study provides a generic approach that can be transferred to regions of different size with comparable land-use types. Carried out in the well-studied cross-border region of Tyrol, our study made use of the rich amount of available scientific data as well as two large-scale questionnaire surveys previously carried out in the study region. Whilst acknowledging that the time and effort required to collect this data from scratch would critically limit the repeatability of the proposed approach, our study underlines the importance of future initiatives for making use of existing data in regions where large volumes of data have already been collected during the last decades. As a central output of our approach, an extensive database covering measures and indicators of ES supply is provided. The compiled database can be used as a baseline according to which changes in ES provision are assessed across land-use types. To monitor changes in ES supply over time, however, future effort is needed to keep this database up-to-date. While ES supply indicators and their values should remain the same, unless new, potentially contradictory scientific findings are provided, new ES supply measures would need to be compiled in the case that new land-use types emerge or new vegetation types occur as a result of climatic changes, e.g. new forest communities that fulfil different functions. Similarly, changes in ES demand need to be monitored over time, for instance at regular intervals of 10–20 years, to consider changes in socio-economic conditions as well as underlying social and cultural values. In the following paragraphs, we provide a more detailed discussion of the individual methodological steps and their associated challenges.

4.2.1. Land-use based approach

Land-use based approaches have several advantages for decision-making, including their simplicity, suitability for cost-effective valuation and possibility to assess impacts of land-use changes on ES (Turner et al., 2003). However, land-use based approaches have repeatedly been criticised as not sufficiently reflecting the ecological functions and processes of the specific area (Eigenbrod et al., 2010; Jacobs et al., 2015). Changes in land-use value are therefore typically reported as the result of changes in the use of land, while assuming uniform distributions of other influencing factors such as topographical factors (e.g. slope inclination) or management regimes (e.g. levels of nitrogen input due to fertilisation). In order to counteract these issues, we used a differentiated classification of land-use types that largely takes specific site characteristics of the individual land-use types into account. For example, permanent cultures occur at low altitudes only and mainly at low to moderate slopes in the study area. Similarly, only slightly inclined areas in the valley bottoms are used for arable land, whereas non-fertilised hay meadows, alpine pastures and abandoned areas predominantly occur on higher and/or steeper sites.

In contrast, forests and fertilised hay meadows are very variable with regard to their site-specific characteristics, specifically in relation to their topographical and climatic conditions. For instance, the capacity of forests to serve as a protection barrier against avalanches, mudflows and rockfalls is low on lower altitudes and slopes with low inclination, but high on higher altitudes and steep slopes (Leitinger et al., 2010; Fromm et al., 2018). Forests at low altitudes, in turn, are generally more capable of producing higher amounts of timber (Niedertscheider et al., 2017). These examples suggest that a more detailed classification of these land-use types, while additionally considering variations in topography and climatic conditions, could provide a more accurate quantification of their ES supply.

4.2.2. ES selection

The selection of ES is critical in a decision-making process as the number and diversity of services considered may lead to different outcomes (Niemeijer and de Groot, 2008; Dick et al., 2014). In our study, we considered the views of regional experts, stakeholders and different users (e.g. visitors and farmers, inhabitants) to guarantee that the most relevant ES for the study area are selected as comprehensively and objectively as possible. Aiming to generate a comprehensive list of key ES, our approach considers both expert knowledge and public knowledge that is often much more local and contextualised. While experts typically consider certain ES according to their formal expert criteria, local land users and society put more emphasis on those services that arise from their immediate interaction with their surroundings (Dick et al., 2014; Bennett, 2016; Lejano and Stokols, 2018). By taking both the perspective of experts and local land users into account for the selection of ES, we aimed to ensure both criteria of salience and legitimacy as suggested by van Oudenhoven et al. (2018). Since this selection is only valid for a certain time and space, the selection of ES needs to be adapted depending on the climatic as well as socio-economic conditions of the regions to which the methodological approach can potentially be transferred. For example, in developing countries, where the local population is most directly dependent on agriculture and forestry (Daw et al., 2011; Fisher et al., 2013), a greater emphasis would need to be paid to provisioning services than done in this study (see van Jaarsveld et al., 2005; Poppy et al., 2014).

4.2.3. Quantification of ES supply

In this work, the ES supply was quantified on the basis of direct and indirect measures derived from existing data sources to consider different relevant aspects of ecosystems and their performance. As we used data from a variety of sources, a central challenge of our approach was to deal with the lack of consistency with regards to the different measurement methods applied. We addressed this issue in two ways. First, we included only work that has been scientifically evaluated or was derived from recognised institutions in the agricultural sector. Second, an attempt was made to consider numerous comparable measurements from different independent studies and average the obtained values for each ES and land-use type.

A further methodological challenge emerged with regard to the attribution of single measures to multiple ES. In particular, the same measures were frequently used to estimate the supply of several ES, as they contribute to not only one but several ES (e.g. naturalness or ecosystem diversity). Given that such an approach can give rise to the problem of double counting, we aimed to reduce the effect of each measure on a single ES by considering as many measures as possible per ES and averaging them to one overall value. As this approach leads to another problem, namely that of the multicollinearity of measures, care was taken in the selection of measures to ensure that they reflect different aspects in terms of content. In some cases, the measures quantified not only the ecosystem's contribution to the service, but also the impact of human and manufactured capital (e.g. the effect of fertilisation) since in many cases the two aspects can hardly be separated. Future research could carry out a differentiated analysis to disentangle the two aspects and their impact on ES provision.

4.2.4. Integration of ES demand

Subjective ES preferences or demand can differ significantly across cultures and individuals, as the evaluation of well-being can depend on both cultural as well as on individual, contextually specific components (Gobster et al., 2007; Agarwala et al., 2014; Dhakal and Kattel, 2019). Among these influential factors, demographic characteristics such as age, gender, education or place of residence are known to be potentially responsible for differences in the response behaviour of individuals (van Zanten et al., 2014). Moreover, external influences such as the current situation of a study participant at the time of an interview might result in different valuations (Gobster et al., 2007). In our study area, significant differences in the attribution of socio-cultural value to ES were found between different stakeholders and demographic groups (Bacher et al., 2016; Zoderer et al., 2016a, 2019a). Moreover, the importance attributed to ES can change depending on people's place of residence; for example, the ES protection against natural hazards may be by far the most important ES for mountain inhabitants but of less importance to people living outside the mountains (Pecher et al., 2017). Even if the differences in people’s desire for ES are small in some cases, they can still lead to conflicts (Zoderer et al., 2019a). For this reason, knowledge of potential conflict provides an important information base suitable for the design of more effective policy interventions such as the conversion of hay meadows into permanent cultures or arable land with related impacts on the ES (Lavorel et al., 2019; Zoderer et al., 2019b).

Within this context, a number of methodological challenges emerged with regard to the assessment of ES demand. First of all, the use of survey results for assessing ES demand may result in potential discrepancies between people’s reported preferences for ES and the consideration of their actual needs. For instance, the public’s preference for carbon sequestration may be low even though they effectively use this service (i.e. CO_2 concentrations are increasing in the atmosphere). Although we find a high public awareness of ES such as climate regulation, probably due to the high media coverage (e.g. on television, newspapers, social media) of these services, a potential under- or overestimation of demand due to such discrepancies would significantly influence the results of this study. Fig. 5 illustrates the potential impact of ES demand on the final land-use type values. It demonstrates that the theoretical range of land-use type values could lie between 1 and 5 after considering the demand. In particular, it indicates that considerable differences in the demand for a single ES could largely result in a different pattern of land-use type values that deviates from that estimated on the basis of ES supply only. Despite this potential impact of ES demand on the final land-use type values, the findings of this study only show minor differences between our integrative approach and that considering the ES supply only. This is likely the case as respondents expressed an overall high demand for ES (values ranged between 3.6 and 4.6) in our study area.

Fig. 5 further shows that the potential impact of ES demand is highest for those land-use types that provide the greatest number of ES at high supply levels. This indicates that the focus of our aggregation method on the diversity of ES rather than the quantity of a few services makes the final assessment specifically sensitive to the number and selection of services considered. While this focus on the plurality of services may be justified from an ecological perspective (de Groot et al., 2010), it potentially underestimates the value people attach to land-use types that only provide few services. Related to this, future research could explore the potential of using a weighting approach as an alternative valuation technique for the assessment of socio-cultural values of ES (i.e. ES demand). For example, survey participants could be asked to assign points to different services on the basis of a limited budget, leaving it open to people how many services they wish to include and which ones to prioritise. This could provide means to better identify which services people actually prioritise from the services considered in this study.

Finally, interviewees were asked about the importance of 19 ES without the possibility to report ES other than those already selected. While this might have led to the exclusion of specific ES of personal relevance from our assessment, we aimed to keep this bias as small as possible by selecting the ES on the basis of a large number of interviews (54 interviews) with different stakeholder groups prior to the survey.

4.3. Practical implementation

This study reveals how different land-use types support the provision of particular ES by providing an information base that can be used for the development of a multi-criteria approach to monitor changes in ES. In particular, it can help to establish a comprehensive understanding of the effect of people's use of land on ES (see also Haines-Young et al., 2012). In the case of a concrete conversion of areas to another use, it is possible to anticipate changes in the ES supply. In line with Navarro and Pereira (2015) and Egarter Vigl et al. (2017), our results indicate, for example, that compared to intensively used land-use types, extensively cultivated or abandoned areas are generally characterised by a higher ES supply, particularly of non-provisioning services. Corroborating the findings of Locatelli et al. (2017), we further demonstrate that land-use intensification often decreases the ES capacity of mountain landscapes, with the exception of services targeted by food or timber intensification. These findings have implications for the management of landscapes in mountain regions in light of current land-use changes. For example, if a region is strongly dependent on tourism, special attention should be paid to cultural services and the maintenance of the cultural landscape (Schirpke et al., 2018a,b; Scholte et al., 2018). This would mean that intensification in agriculture should be halted or reversed, but also extensive reforestation may reduce the attractiveness of the area as housing and living space (Grêt-Regamey et al., 2008). Regions that are rather independent from tourism with agriculturally favourable sites could increasingly be used for the production of provisioning services, whereas agriculturally unfavourable sites could be optimised in terms of regulation & maintenance services by reforestation. In this way, it would be possible to decide from area to area, according to local and regional priorities, which future developments might be the best with regard to the ES. Such comparisons between land-use types can be used to analyse similarities and demonstrate causal relationships in future scenarios (see also Tallis and Kareiva, 2006) and are therefore particularly important for policy-makers (TEEB, 2010; Lavorel et al., 2019). In particular, the inclusion of user demand can increase the probability of a successful incorporation of ES in the decision-making process (van Oudenhoven et al., 2018).

To date, most decision-makers have found it difficult to replicate the results of the large number of recent ES assessments and to integrate them into their decisions (Lavorel et al., 2019). The immense time and resource constraints needed for data collection and analysis limits the realisation of holistic assessments of ES (Scolozzi et al., 2012; Dick et al., 2014). It is therefore not surprising that in most cases, environment and resource management strategies are driven by approaches addressing individual factors or individual ES, while a range of other factors and services remain disregarded (Tallis and Polasky, 2011). For instance, strategies for increasing crop production often risk fostering the extension of cultivated land without considering its negative impacts on the many regulating services (e.g., erosion control, habitat and biodiversity loss, soil fertility) that were originally provided by forests or grasslands. In many cases, there is no clear understanding of the mechanisms behind the positive associations and negative associations of ES (Schirpke et al., 2019). The consequences associated with interactions are often not visible enough for decision-makers to make balanced decisions (Jopke et al., 2015). The use of a land-use based approach, such as we propose in this work, can therefore be an important tool.

The study presented can also be helpful in supporting the design and implementation of payment schemes for agriculture. The EU spends a considerable amount, about 40% of the total EU budget, on agriculture (see ec.europa.eu/info/food-farming-fisheries/). This expenditure, however, has often been criticised for its focus on an economically powerful sector that accounts for less than 2% of EU GDP and that causes environmental problems and regressive redistribution problems (Bennet et al., 2006). Despite these side-effects, agriculture supplies the population with food, other public goods such as cultural landscapes and leisure areas, and significantly contributes to the quality of life in rural areas. Nevertheless, our study reveals that there are serious differences between agricultural land-use types in terms of the ES they can provide. In particular, our approach reveals that in contrast to intensively used agricultural land, extensively used hay meadows and low-input pastures are not only valuable for their production of agricultural goods but also for their provision of many regulating and cultural services important for society. In this context, our results can serve as an important information base suitable for informing the development of better targeted support policies, as well as for the support of existing ones. In addition to consideration of the supply of ES, society's demand for ES as noted in our approach can foster the design and implementation of socially just and legitimate subsidy programmes (Watson, 2005). Our findings thus call for the design of financial programmes to support agriculture and forestry on the basis of the ES provided. Subsidy programmes could be designed at both the regional and local level as a function of the ES delivered by a particular land use and the value society attributes to them. The consideration of ES as an argumentation aid in the design and implementation of subsidies would not just make ES visible to society, but also increase the transparency and legitimisation of money flows. At the same time, such an approach would provide greater flexibility for the individual land user and recognise his or her role as an active producer of important provisioning, regulating and cultural ES rather than as passive recipient of support.

5. Conclusions

This study proposed an innovative approach for comprehensively assessing the value of land-use types from the perspective of multiple ES and communicating these values at different levels of aggregation. Designed as a decision-support tool, the approach enables the comparison of different land-use alternatives, while taking both the biophysical capacities for ES provision and socio-cultural values of the same services into account. The key features of the approach, namely to quantify the value of land-use types by integrating both the supply and demand of multiple ES, have been made possible by using and collating large amounts of available data, which until now have largely remained fragmented. This underlines that future ES research could benefit from the establishment of initiatives to collect and combine the many indicators and data available to allow a comprehensive assessment of several ES. A step in this direction is the task of the MAES working group under Action 5 of the EU Biodiversity Strategy to 2020, which provides guidelines on how to best use existing knowledge and data to derive indicators for quantifying and mapping the condition of ecosystems and their services at European level (Maes et al., 2016). In particular, coordinated efforts are required to construct integrated meta-databases at the regional, national and continental level, compiling existing ES indicators and storing the vast amount of data needed for their development. The database presented in this study (published online: http://www.eurac.edu/en/research/mountains/alpenv/services/) has the potential to evolve into an adaptable and interactive tool for transdisciplinary assessments. This creates opportunities to interactively adjust and verify the links between indicators and individual services depending on site-specific conditions, and to modify the selection of ES and weighting criteria to meet the specific needs of the decision-making context. The establishment of such databases may be a first step towards integrating the extensive knowledge accumulated so far from various scientific disciplines in the field of ES research and supporting the operationalisation of this knowledge in practice.

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

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