

Research

Conservation with local people: medicinal plants as cultural keystone species in the Southern Alps

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ABSTRACT. The concept of “cultural keystone species” (CKS) combines ecological and socioeconomic aspects and has a great potential for improving the overall success of conservation and restoration of ecosystems. In our study, we combined an ecological analysis of traditional medicinal plant species with an explorative analysis of the stakeholder landscape to understand the importance of plants for local communities. We investigate the feasibility of the CKS concept for traditional medicinal plants using the Southern Alps (Northern Italy) as a case study. Based on a comprehensive survey of traditional medicinal plants, we analyzed the habitats where they occur and their significance as CKS candidates. We applied the index of identified cultural influence (ICI). We identified some of the relevant stakeholders and their potential interest in traditional medicinal plants. From a total of 273 native medicinal species, we ranked the 10 most important CKS candidates. These comprised species with different ecology such as the herbs *Achillea millefolium* agg., *Alchemilla xanthochlora*, *Arnica montana*, *Hypericum perforatum*, *Matricaria chamomilla*, *Peucedanum ostruthium*, *Urtica dioica*, the shrub *Juniperus communis*, and the tree species *Betula pendula*. By merging their importance for the local communities with their occurrences in the habitats of South Tyrol, the concept of CKS can stimulate species and habitat conservation, and ecosystem restoration.

Key Words: *ecosystem restoration; ethnobotany; ethnomedicine; nature conservation; traditional medicine; vascular plants*

INTRODUCTION

Despite manifold efforts at the national and international level, biodiversity is rapidly declining worldwide (Chapin et al. 2000, Butchart et al. 2010, IPBES 2019). There is evidence that this loss of biodiversity will lead to subsequent alterations in ecosystem functioning and ecosystem stability (Naeem et al. 2009). Biodiversity loss diminishes human well-being by decreasing the services that species and ecosystems can provide for people (MEA 2005, TEEB. 2010). Direct or indirect human impacts on ecosystems, in particular land-use changes and intensification, biological invasions, eutrophication, and climate change are considered the major causes of biodiversity decline (Butchart et al. 2010, IPBES 2019). Additionally, there is a continuous shift of the human population worldwide from traditional cultural landscapes toward cities (Antrop 2004, McDonald et al. 2008, Zerbe 2022). Accordingly, formerly multifunctional cultural landscapes are subject to land-use intensification or become abandoned while urbanization increases (Price et al. 2015, IPBES 2019). This is particularly true in mountain areas like the Alps (Perlik and Messerli 2004, McDonald et al. 2008).

Conventional biodiversity conservation focuses on ecological parameters (Garibaldi 2009), i.e., plant and animal species that represent the ecological functioning, stability, and integrity of an ecosystem (Caro and Girling 2010). However, these parameters often overlook or neglect cultural aspects of the ecosystem's genesis that is frequently strongly shaped by local culture and land-use history (Hunn et al. 2010, Zerbe 2019, Janišová et al. 2021). For example, extensively managed grasslands, so-called “low-input grasslands,” in Central Europe are shaped by centuries to millennia of land use (Hejman et al. 2013, Bonari et al. 2017, Leuschner and Ellenberg 2017), and yet they persist and enjoy extraordinary species richness (Wilson et al. 2012, Habel et al. 2013, Chytrý et al. 2015). Moreover, species conservation and

ecosystem restoration efforts should be meaningful also to the local people and thus considerations can go beyond ecological functionality and address the associated socioeconomic factors (Zerbe 2019) to meet the three pillars of sustainability (Purvis et al. 2019).

The concept of cultural keystone species (CKS) was introduced by Nabhan and Carr (1994) and adapted for biocultural conservation by Garibaldi and Turner (2004). This approach focuses as a “metaphorical parallel” (Garibaldi and Turner 2004) to the ecological keystone species concept (Paine 1969, Hale and Koprowski 2018) on plant and animal species whose existence plays a central role in the identity of the culture of a local community. These species fulfill fundamental roles in material, diet, medicines, and/or spiritual practices (Garibaldi and Turner 2004, Coe and Gaoue 2020a). Their occurrence, use, and symbolic value are, thus, considered essential for local communities (Cristancho and Vining 2004). Although the exact definition of CKS and the methodologies to identify and analyze CKSs are still under debate, including criticisms on incorporated researcher subjectivity (Garibaldi and Turner 2004, Davic 2004, Coe and Gaoue 2020b), this concept bridges ecology and social science by combining ecological and socioeconomic approaches in the practice of nature conservation and ecosystem restoration. The concept may serve as an entry point for a community of people to reflect on and design their unique set of sustainable livelihood indicators (Jackson and Jain 2006). Also from an ecological point of view, CKSs are recognized as effective starting points for biodiversity conservation and habitat restoration because they build upon traditional ecological knowledge (TEK; Berkes et al. 2000).

The CKS concept aims to predict plant and animal species that are culturally important, e.g., that play a role in resource acquisition, fulfill a psycho-socio-cultural function within a given

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culture, have a high-use value, and an associated naming and terminology in a native language (Cristancho and Vining 2004, Garibaldi and Turner 2004, Coe and Gaoue 2020a). Additionally, a high level of species irreplaceability qualifies for CKS designation. Applying the concept of ecosystem services to the species level, it would follow that these species supply provisioning, regulating, and cultural services (MEA 2005, Haines-Young and Potschin 2010). Species used in manifold ways have become multi-purpose species (Stewart and Salazar 1992, Pant and Samant 2006). Based on a review, Coe and Gaoue (2020b) highlighted that most studies on CKSs in human societies fail to provide a robust and reproducible way to measure the cultural importance of a species and thus the identification as CKS itself.

To assess the cultural significance of plant species, Tardío and Pardo-De-Santayana (2008) coined the cultural importance index (CI). This index combines the diversity of uses of plant species and the number of informants mentioning them. With a similar objective, namely, to promote species conservation and embedding this into local communities, the index of cultural significance (ICS) was introduced by Turner (1988) and applied for the analysis of the importance of plants of particular cultural significance (Stoffle et al. 1990, Da Silva et al. 2006, Helida et al. 2015). All these indices have been formulated and used in efforts to preserve biodiversity based on the local knowledge and on the cultural significance of plants in local environments. Furthermore, these indices and their application do also contribute to a transdisciplinary interaction of scientific disciplines of the social and natural sciences as ecologists and anthropologists integrate their expertise.

Multi-purpose plant species might be strongly related to the diversity of species and land-use systems (Salick et al. 1999, Schippmann et al. 2002, Grabherr 2009). Among the manifold purposes and uses, medicinal plants play a central role (Hamilton 2004), and are estimated to account for more than 12% of the global flora (Schippmann et al. 2002). In the European Alps, medicinal plants are an integral part of the traditional alpine culture and are highly valued both in folk medicine and in modern evidence-based medicine (Petelka et al. 2020).

We aim at contributing to filling a research gap on the CKS concept at the geographical and conceptual levels (Coe and Gaoue 2020b). As a case study in this context, we selected South Tyrol, a region in the Southern Alps (Northern Italy) that is well known for its unique cultural and natural diversity (Minerbi and Hellrigl 2004). We explored whether the CKS concept adapted to traditional medicinal plants offers a synergy between local culture, species, and habitat conservation. If confirmed, this connection might facilitate nature conservation efforts by rooting them in the local communities. We explore the potential of traditional medicinal plants as CKS candidates for the practice of nature conservation and ecosystem restoration strategies. Additionally, we want to identify stakeholders with their interests and their role in promoting CKSs, because knowledge transfer, decision-making processes, and nature conservation action are strongly bound to local and regional communities and actors (Reed 2008, Sterling et al. 2017). Accordingly, we analyze and evaluate ecological and ethnobotanical information on medicinal plant species in South Tyrol to identify plant species that simultaneously show high values in cultural and ecological aspects

selected from the pool of inherent traditional medicinal plants. We performed expert interviews to provide a first draft of the local stakeholder landscape, to explore stakeholders with their interests and influence to promote knowledge transfer and decision-making processes for a sustainable resource management regarding medicinal plant species and their role in nature conservation and ecosystem restoration. Reflecting on this case, we discuss synergies between goals emerging from different perspectives of landscape science such as biodiversity conservation and the strengthening of the cultural identity of local communities.

MATERIALS AND METHODS

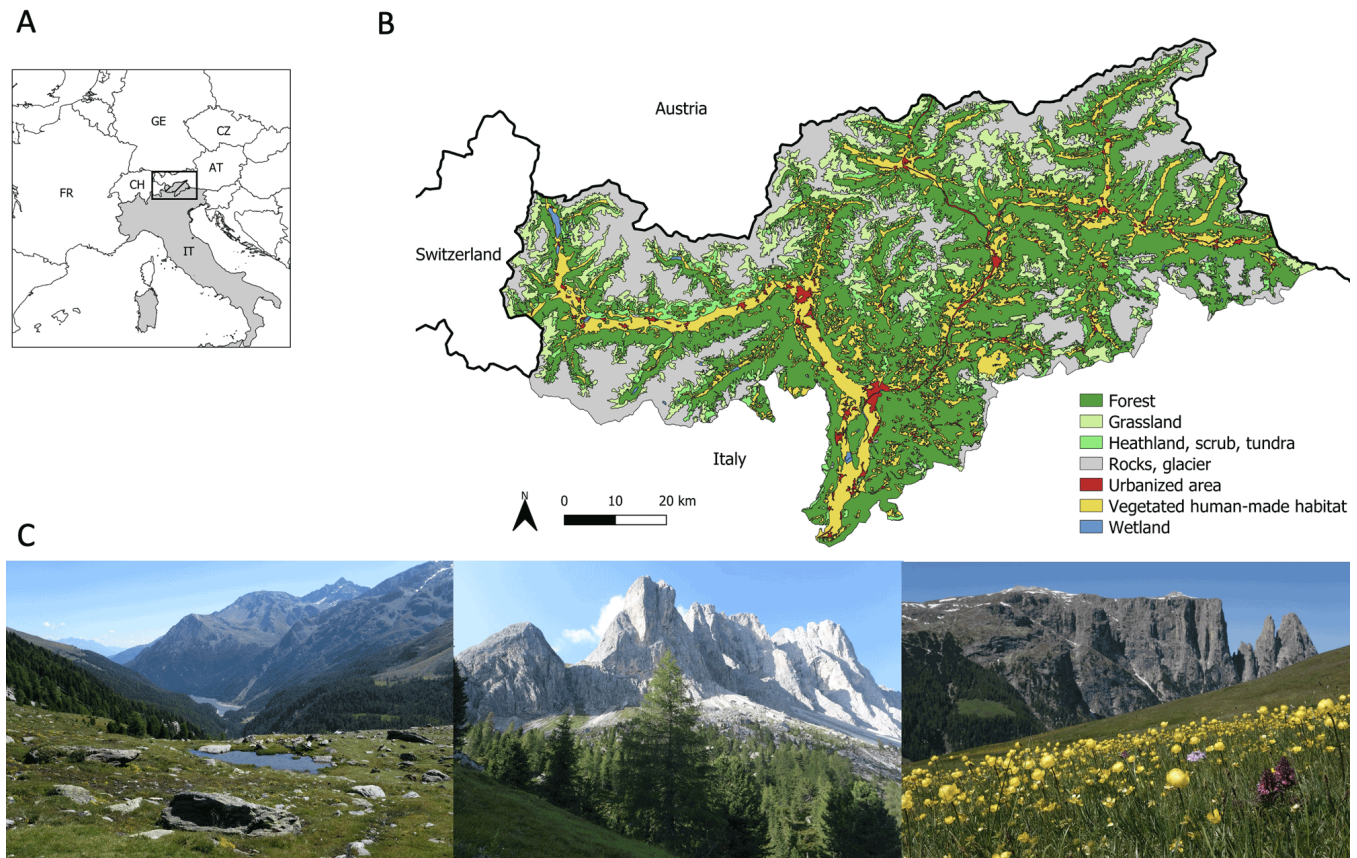
Study area

Our study area is South Tyrol in the Southern Alps, which is the northernmost province of Italy. In the mountainous region of South Tyrol, about 40% of the entire area is located above 2000 m a.s.l., with an altitudinal range of 194 m a.s.l. to a maximum of 3893 m a.s.l., which is the peak of Ortler Mountain. Approximately half of the landscape of South Tyrol is covered by forests, predominantly spruce (*Picea abies*) and pine forests (*Pinus sylvestris*, *P. cembra*). Agricultural land covers 32.5% of South Tyrol, out of which more than a third (38.9%) is intensively used as alpine pastures, vineyards, and apple orchards. The remaining area is made up of alpine grasslands, rocky areas, and glaciers (13.8% of the overall province), wetlands and water bodies (< 1%), and urban settlements with about 3% are mostly below 1200 m a.s.l. (ASTAT 2018). Because of the elevational range, the heterogeneous geomorphology, and the location in the Southern Alps, the study area shows a high variety of different climatic features (Pesaresi et al. 2017).

The variability of the natural and cultural environments that compose the main macro-habitat types are forests, grasslands, scrub and heathlands, man-made areas (e.g., urbanized and agricultural areas or gardens), and wetlands (Fig. 1), and support a very rich and diverse flora with 2169 native plant species including many rare and endemic species (Wilhelm et al. 2006a). Currently, about 25% of these species are endangered or threatened and appear on the Red List (Wilhelm and Hilpold 2006). Additionally, South Tyrol harbors currently about 400 non-indigenous species (Wilhelm et al. 2006a).

Also culturally, South Tyrol is a highly diverse region at the political border between Italy and Austria with numerous cultural influences throughout the past centuries. Over 300,000 native German (70%), 100,000 Italian (26%), and 20,000 native Ladin (4%) speakers live in South Tyrol (population census of 2011, ASTAT 2018). After being a part of the Habsburg Empire for centuries, South Tyrol and the neighboring Trentino became part of Italy after World War I followed by Italianization measures under Mussolini and now has an autonomous regional government under the Italian state (Steininger 2003, Lantschner 2008) with a power-sharing system across the linguistic groups that successfully deals with ethnic diversity, resolves potential conflicts, and encourages interethnic cooperation (Alber 2017, Carlà 2015, 2022). The South Tyrolean society encompasses three clearly distinct linguistic groups. Ladin speakers live mainly in two valleys and Italian speakers mainly in the urban areas, especially in the South Tyrolean capital Bolzano/Bozen (Carla 2022). Until the late 19th century, the people of South Tyrol were

Fig. 1. (A) Overview of the South Tyrol study site within Central Europe with the macro-habitats (B) and photographic impressions of typical habitats (C). The map is based on Corine land cover data from <https://land.copernicus.eu/>.



characterized by secluded mountain farmers, smallholders, and family farms. The use of local medicinal plants was the most important and often the only possibility to cure illnesses and health problems. Accordingly, unique medicinal customs and traditions developed, and medicinal plants became integral parts of the culture (Pickl-Herk 1995). Wild plant gathering is a longstanding activity and tradition in South Tyrol, which was often part of the childhood of local herb farmers, who in turn enjoy passing on their knowledge about wild plants to interested children and adults, and offer guided walks and courses or talks on their therapeutic effects (Schunko et al. 2019).

Expert interviews

We used an explorative approach of qualitative, semi-structured, one-on-one interviews (Lamnek 1995, Ryan et al. 2009) to provide insights from relevant stakeholders, their role, and their evaluation with regard to traditional medicinal plants as CKS candidates. Stakeholders were identified following Reed et al. (2009). With this approach, each interviewee can elaborate on their own terms, unfolding points of deeper meaning within an individual's statement. In general, expert statements are regularly dependent on and validated by individuals' contexts, experiences, and interests. Thus, this is a first step in exploring the stakeholder landscape, gaining first-hand insights, and leading to the first draft of a power-interest mapping.

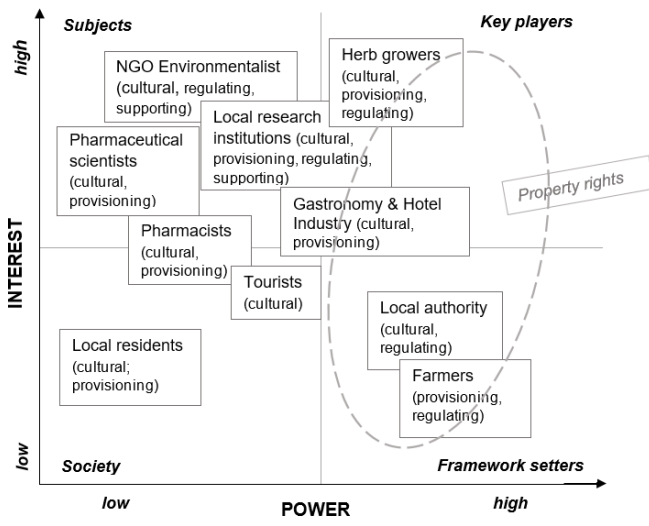
We started with medicinal herb growers and selected further experts based on their local and regional reputation as book authors on traditional medicinal plants and followed the recommendations of the previously identified experts. When first contacting potential respondents, the interviewer explained the scope of the study and inquired about their willingness to participate in the interview, assuring measures to protect confidentiality. Consent to participate also included the right to withdraw the recording. Some participants allowed only bullet-point notes by the interviewer. While maintaining confidentiality, all data were anonymized in a protected space. All data were deleted after processing and analysis. We interviewed herb farmers ($N = 6$), pharmacists ($N = 4$), a historian ($N = 1$), and a local botanist ($N = 1$). Information on the stakeholders was mainly collected through semi-structured interviews following these questions:

1. Who do you consider relevant for the topic of traditional medicinal plants in South Tyrol?
2. How do you rate the interest and influence of traditional medicinal plants?
3. Which South Tyrolean medicinal plant do you consider to be the most important for medicinal purposes?
4. Which South Tyrolean plant do you consider culturally most important with regard to intensity or multiplicity of use,

ceremonies, legends, symbols, history, trade, and irreplaceability?

The first two questions were related to developing the power-interest map (Fig. 2), whereas questions 3 and 4 provided information on the ranking of identified cultural influence (ICI).

Fig. 2. Power-interest map showing the stakeholders with regard to traditional medicinal plants in the region of South Tyrol (Northern Italy); the oval indicates property rights. The ecosystem services that are mainly appreciated by each stakeholder group are given in brackets.



Data analyses

To explore and characterize plant species that are inherently of high cultural and ecological significance to the people of South Tyrol, we used a list of 273 species with 267 vascular plants, 3 mushrooms, and 3 lichens, considered as traditional medicinal species (for details on the generation of the dataset see Petelka et al. 2020). Assuming that all traditional medicinal plants, fungi, and lichens are potential CKSs, we performed all analyses starting from this list. To understand whether there are patterns in environmental features of CKS plant occurrence, i.e., to understand where the CKS candidates occur, we related CKS candidate species to their preferential habitat(s) of occurrence. We used the statistically derived characteristic species combination of EUNIS habitats (Chytrý et al. 2020). In phytosociology, the term “characteristic species combination” is defined as a combination of diagnostic species and species with higher constancy that together define a vegetation unit (Braun-Blanquet 1964, Chytrý et al. 2020). In this study, we use this term to identify diagnostic, constant, and dominant species that are useful to characterize different vegetation types (Chytrý and Tichý 2003). We deleted all habitats that do not occur in the study area. Then, we matched the predefined species list with their occurrences in habitats (Chytrý et al. 2020). We counted the occurrences derived from the characteristic species combination of each habitat on the basis of diagnostic, constant, and dominant species (Chytrý et al. 2020). We repeated the analysis for all occurrences and for dominant species only. We analyzed

separately the information about dominant species because dominant species are those that often reach high cover in a particular habitat, determining the habitat physiognomy (Chytrý et al. 2020), and thus being a crucial candidate to become a CKS. This latter analysis was done to explore the possible role of the species’ dominance in a given community, under the assumption that people might be attracted to a certain species not only for their use of its intrinsic properties, but also for its dominant (physical) aspect (see ecological apparency hypothesis, e.g., Lucena et al. 2007, 2012 or the resource availability hypothesis, e.g., Gaoue et al. 2017, Hart et al. 2017).

In the next step, we grouped the habitats where CKS candidates occur using five macro-habitats (i.e. forest, grassland, man-made habitat, scrub, and wetland; Fig. 1). This grouping operation was done according to the hierarchical classification of EUNIS habitats (Chytrý et al. 2020). Further, this classification also widely corresponds to the main physiognomic types that are also more easily recognizable by local people. To outline the ecological preferences of CKS candidates in the context of their preferential habitat(s), we used the Ellenberg indicator values (EIV; Leuschner and Ellenberg 2017), modified for the Italian flora (Pignatti et al. 2017-2019). We repeated the analysis for all occurrences and for dominant species separately. In all analyses, three fungi and three lichens were deleted, as well as 60 plant species that were not part of any characteristic species combination of EUNIS habitats (Chytrý et al. 2020).

We adapted qualitative content analysis methodology (Mayring 2008, Kuckartz 2012) for extracting the information regarding stakeholder identification, power interest mapping, and the ICI evaluation from the interviews in the following steps: (i) highlight important text sections and write memos; (ii) identify thematic categories regarding (a) stakeholders and their position within the power interest map and (b) regarding the ICI; (iii) cluster and code text passages according to these categories for further analysis and visualization.

Finally, we applied the index of ICI, a quantitative evaluation matrix to determine a species “keystone-ness” (Garibaldi and Turner 2004) to the list of CKS candidates (Table 1). The ICI matrix table combines six cultural elements: (1) intensity or multiplicity of use; (2) naming and terminology in a language; (3) role in narrative, ceremonies, or symbolism; (4) persistence in cultural change; (5) level of a unique position in the community; and (6) opportunities for resource acquisition, with each element containing specific questions to extract a quantitative cultural value (CV) of species, the so-called “keystone-ness.” The rating scale for each question was based on six possible responses (Table 1).

Each interviewee was asked to provide a ranking (e.g., number of uses, citation frequency, vernacular names; Table 1) or a verbal evaluation of a ranking (more important, less important). In those cases where the experts did not agree, the ratings were based on a discussion process among the authors, which also assessed the respective literature. As a result, based on the ICI evaluation process, we evaluated all information gathered from the literature review and interviews, summed up the number of elements for each species to yield a total CV score, and proposed a final set of 10 CKS candidates. Thus, the ranking depended on the subjective

Table 1. Ranking of 25 preliminary selected South Tyrolean cultural keystone species (CKS) candidates according to the index of identified cultural influence (ICI). Suggested rating question responses based on the following: 5 [yes, very high], 4 [yes, high], 3 [yes, moderate], 2 [yes, low], 1 [yes, though very low or infrequent], 0 [no, not used] (Garibaldi and Turner 2004). For details see Materials and Methods.

Species	Elements that indicate a cultural keystone						Total Score (ICI rating) out of 35
	1. Intensity, type and multiplicity of use		2. Naming and terminology in a language, including use as seasonal or phenological indicators, names of months or seasons, place names	3. Role in narratives, ceremonies, or symbolism.	4. Persistence and memory of use in relationship to cultural change	5. Level of unique position in culture (i.e. it is difficult to replace it with other available native species)	
	Is the species used intensively (routinely, and/or in large quantities)?	Does the species have multiple uses?	Does the language incorporate names and specialized vocabulary related to the species?	Is it prominently featured in narratives and/or ceremonies, dances, songs, or as a major crest, totem, or symbol?	Is the species ubiquitous in the collective cultural consciousness and frequently discussed?	6. Extent to which it provides opportunities for resource acquisition from beyond the territory Is it used as a trade item for other groups?	
<i>Arnica montana</i>	5	4	5	5	4	5	33
<i>Hypericum perforatum</i>	5	5	5	5	5	4	33
<i>Juniperus communis</i> subsp. <i>communis</i>	5	4	5	5	3	5	32
<i>Sambucus nigra</i>	5	5	4	4	3	4	28
<i>Urtica dioica</i>	5	5	3	4	5	4	28
<i>Achillea millefolium</i> aggr.	5	5	5	4	2	3	27
<i>Matricaria chamomilla</i>	5	5	3	4	3	3	27
<i>Betula pendula</i>	3	5	4	5	1	5	25
<i>Peucedanum ostruthium</i>	3	4	4	5	3	5	25
<i>Alchemilla xanthochlora</i>	3	4	5	5	2	2	24
<i>Artemisia absinthium</i>	5	5	1	4	1	4	23
<i>Thymus pulegioides</i>	5	5	3	4	1	2	23
<i>Taraxacum</i> sect. <i>Taraxacum</i>	5	2	3	3	3	3	22
<i>Valeriana officinalis</i>	5	2	3	4	3	3	22
<i>Gentiana lutea</i>	2	3	1	3	3	5	21
<i>Malva sylvestris</i>	5	4	2	3	1	3	21
<i>Plantago lanceolata</i>	5	3	1	4	4	2	21
<i>Rosa canina</i>	5	3	2	4	2	2	21
<i>Verbascum densiflorum</i>	5	3	3	3	1	3	21
<i>Crataegus monogyna</i>	2	3	3	5	1	3	20
<i>Tilia cordata</i>	3	2	2	5	1	4	20
<i>Argentina anserina</i>	5	3	2	3	1	2	17
<i>Equisetum arvense</i>	1	5	2	3	3	3	17
<i>Achillea erba-rotta</i> subsp. <i>moschata</i>	0	4	2	2	1	2	14
<i>Angelica sylvestris</i>	0	3	3	3	1	2	13

knowledge of the interviews and authors and the information gathered by the literature review (Petelka et al. 2020 and citations therein).

Furthermore, we classified the information on the stakeholder landscape gathered from the interviews and literature in a power-interest map that displayed their attributes and interrelationships. Subsequently, the ecosystem framework was applied in order to identify and classify stakeholders according to their interest in the goods and services provided by the supporting, regulating, provisioning, and cultural functions of the plants. The stakeholders had no active involvement in constructing the power-interest map.

Nomenclature of species was standardized according to the Euro+Med Plantbase (2021). Endangerment and protection status of species was vetted through the online platform “Flora Fauna Südtirol” (Wilhelm et al. 2006b) for vascular plants, and the “Information System on Italian Lichens” (Nimis 2022), the Italian Mycological Association (Index Fungorum 2022, [http://](http://www.indexfungorum.org/names/names.asp)

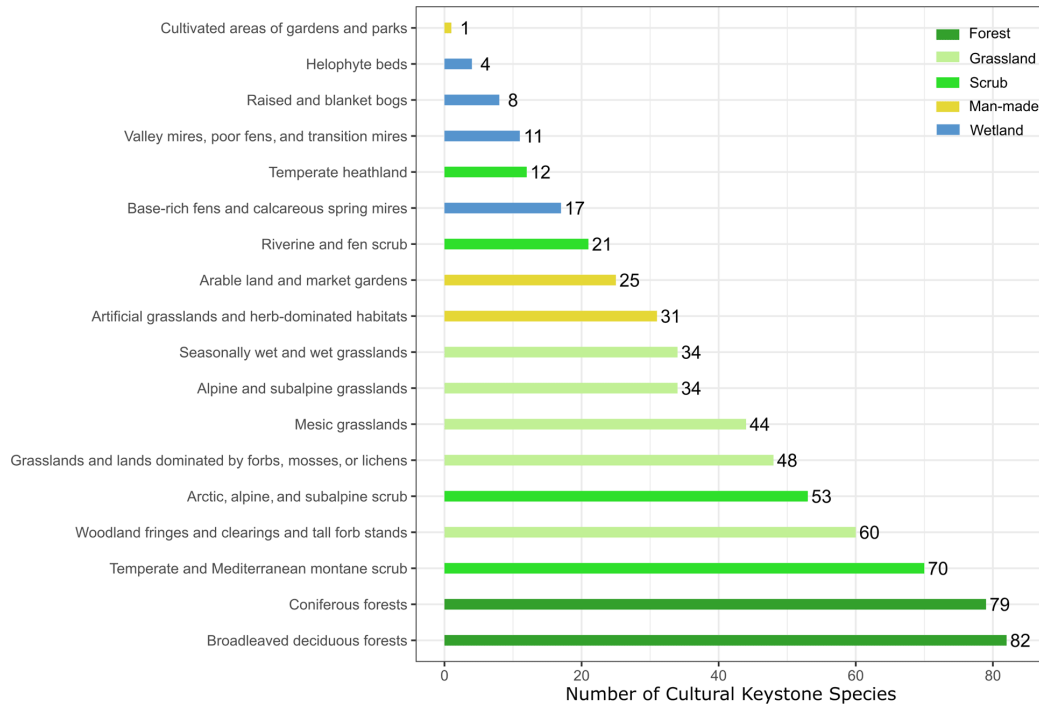
www.indexfungorum.org/names/names.asp), and the IUCN Red List of Threatened Plants (IUCN 2020) for lichen and mushrooms. Phytochemical or pharmacological evidence of the medicinal healing effect of plant substances and medicinal products was determined by monographs of the European Medicines Agency (EMA 2021). To map the number of CKS candidates per macro-habitat in South Tyrol, we used Corine land cover data from <https://land.copernicus.eu/>. Analyses were done using R v. 3.6.1 (R Core Team 2020). Maps were created using a 1-km radius using ArcGis v.10.3.1 (ESRI 2016),

RESULTS

Stakeholders and drafting a power-interest map

Our analysis revealed that in the past, farmers interested in production (mainly fodder) were the key players, holding property rights through land ownership. Today, however, a broad field of stakeholders with interests in production, culture, and information were raising claims on traditional medicinal plants, including the land on which they grow.

Fig. 3. Frequency of all occurrences of the cultural keystone species (CKS) candidates per habitat. CKS species are related to their preferential habitat(s) of occurrence. We used the statistically derived characteristic species combination of EUNIS habitats (for details see Chytrý et al. 2020). Colors refer to the macro-habitat categories.



Crucial stakeholders are herb farmers, who cultivate herbs mostly organically; conventional farmers performing a highly intensified crop production; gastronomy and hotel industry that often use marketing of traditional medicinal plants and practices; pharmaceutical industry that develops and patents new drugs based on traditional medicinal plants; environmental NGOs promoting biodiversity, resource protection, species and habitat conservation; tourists, who are attracted by the aesthetic and cultural uniqueness of traditional medicinal plants and their habitats; local authorities, who aim to preserve local identity, culture, and land use regulations; and, last but not least, local residents. They can be grouped into individual subjects, groups/society, framework setters, and key players.

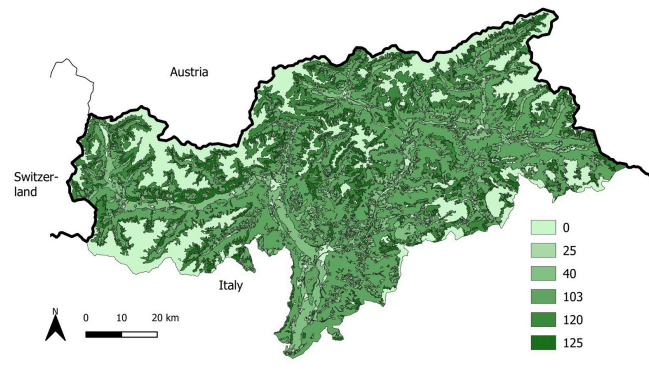
We differentiate power and interests of those stakeholders (Fig. 2). Some very engaged local actors such as NGOs, pharmaceutical scientists, and research institutions are highly interested and should be involved strategically in the mainstreaming of knowledge on benefits provided by traditional medicinal plants. They can effectively support current key players and encourage especially local society and authority to become key players in promoting medicinal plants as CKSs. Currently, the power and interests of both local residents and authorities were considered low with regard to traditional medicinal plants, whereas herb growers and the users (e.g., gastronomy) have a high interest and are powerful key players in South Tyrol. Part of those stakeholders holds property rights on traditional medicinal plants.

Herb farmers are in constant conflict with conventional farmers because the pesticide drifts pose a severe obstacle to meeting the thresholds for selling their organically produced herbs. Environmentalists and local nature conservation agencies were bargaining with conventional farms for the maintenance and protection of habitats for wild-growing medicinal plants. Some stakeholders were exerting their influence through strategic liaisons with key players and legal authorities, respectively. However, the interest of local residents and the local authority was perceived as minor compared to other stakeholders (Fig. 2). The pharmaceutical industry, for example, as a powerful global player has pursued its monopoly for the production and trade of pharmaceuticals by acquiring legal standards with the Health Agency for the purpose of outcompeting traditional medicinal plants and products from the market.

Occurrence of CKS candidates in South Tyrolian habitats

Overall, we found 267 species that are considered as part of at least one specific characteristic combination either as diagnostic, constant, or dominant in habitats. These species occur 634 times in 18 sub-habitats belonging to 5 macro-habitats (Fig. 3 and Fig. 4), while dominant species occurrences were 92 distributed in 15 sub-habitats (Fig. 5). Occurrences for all habitats are reported in Appendix I. We did not find a clear pattern for Ellenberg indicator values (EIVs) for all occurrences (Appendix 2). EIVs for occurrences of dominant species showed a large variability across indicators and habitats (Fig. 6).

Fig. 4. Number of cultural keystone species candidates per macro-habitat in South Tyrol (based on Corine land cover data from <https://land.copernicus.eu/>).



Index of identified cultural influence (ICI)

The evaluation matrix for the index of identified cultural influence (ICI) for the 25 preliminary selected species is reported in Table 1.

Diversity of medicinal plants and potential cultural keystone species in South Tyrol

We summarized the characteristics of the 10 highest-ranked medicinal plant species based on the ICI identified from a total of 273 species used in traditional folk medicine in South Tyrol (Table 2). The set of species includes seven herbs and three trees belonging to seven different plant families, most frequently to the Asteraceae. The use versatility was high among the species, ranging from three to six purposes. Nine out of the 10 plants were used as multi-contextual remedies for several disorders (more than five categories) and thus were often referred to as universal remedies (in German: *Allheilmittel* or *Heil aller Schäden*). According to 12 International Classification of Primary Care (ICPC)-2 disease categories, the most frequent therapeutic uses in traditional medicine were for digestive, respiratory, and integumentary systems. For 8 of the 10 species (except for *Peucedanum ostruthium* and *Alchemilla xanthochlora*), traditional uses have been scientifically validated and approved as herbal medicinal products (EMA 2021). Side effects or interactions with other drugs were reported for three species (*Arnica montana*, *Hypericum perforatum*, and *Juniperus communis* subsp. *communis*). Vernacular names of the species ranged from four to as many as 18. Moreover, all plants (except for *P. ostruthium*) were cultivated in traditional home gardens. In the study area, none of the 10 CKS candidates were assigned to one of the five threat categories of the IUCN Red List, with the exception of *Arnica montana* on which a partial local protection status was imposed, meaning that for the extraction from nature a permit from the regional authority must be obtained. All identified CKS candidates showed a high use versatility and besides the medicinal application they were also used as alimentary, for veterinary purposes, spirituality and cults, as cosmetics, and for domestic use. The highest versatility was shown by the perennial herbs *Alchemilla xanthochlora*, *Hypericum perforatum*, *Urtica dioica*, and the woody species *Betula pendula* and *Sambucus nigra*.

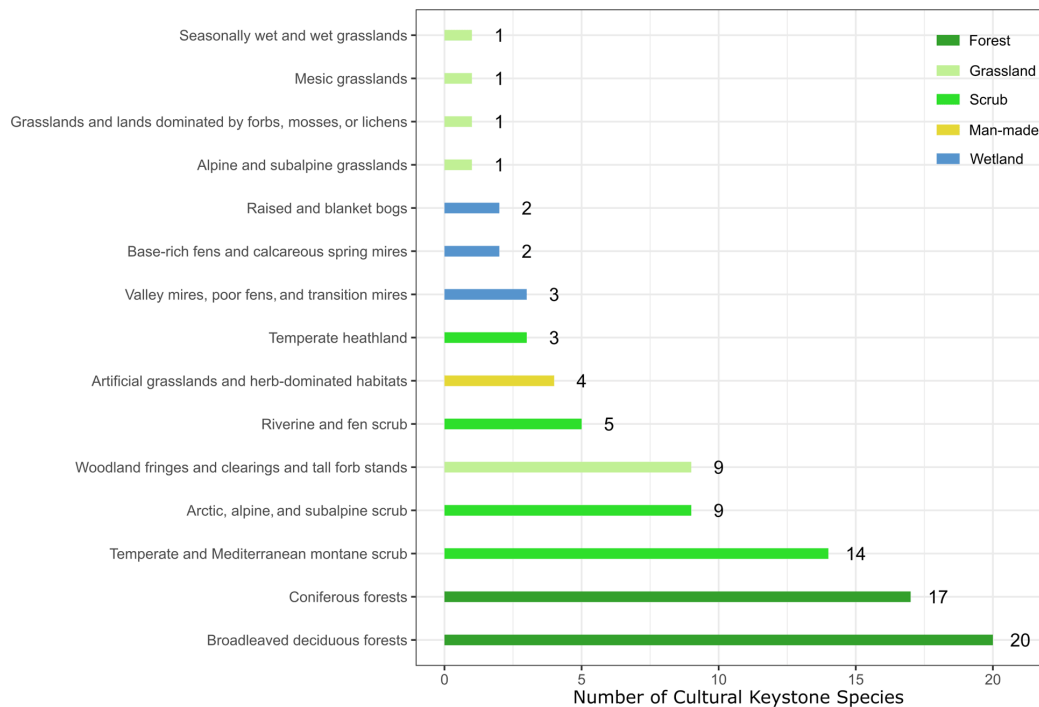
DISCUSSION

We applied the CKS approach in a mountainous region of the European Alps to identify plant species that simultaneously show a high value in cultural and ecological aspects selected from the pool of inherent traditional medicinal plants. Our main findings relating to the habitats of the potential CKSs can be summarized as follows. CKS candidates usually occur in species-rich habitats, but mostly in common habitats such as, e.g., mesic grassland and various forest communities. Because CKS candidates mostly occur in dry to mesic habitats, they are easily accessible for collection as medicinal plants. Many traditional medicinal plant species that occur on grassland are hardly recognizable for non-specialists and this might have constrained their use and their potential for becoming a CKS. A broad spectrum of interest groups, of individuals or groups, have an interest in traditional medicinal plants and put this claim into practice with specific powers of assertion (Fig. 2). Commercial gathering and processing of wild medicinal plants is highly regulated, e.g., a compulsory qualification of the persons involved, gathering permits, or the number of species collected to prevent overharvesting (Schunko et al. 2019).

The more and diverse stakeholders who seek their entitlements to serve their interests in environmental resources, the more conflicts arise that have stimulated studies on strategies of how to solve those challenges (Redpath et al. 2013, Young et al. 2016, Rechciński et al. 2019). In South Tyrol, the use of pesticides by conventional farmers impacts on neighboring farms aiming to produce herbs in accordance with European organic farming regulations, including the clauses on wild plant gathering (Schunko et al. 2019). This is a particular problem in South Tyrol where there are large highly intensive areas for apple and grape production with a frequently high input of pesticides (Favaro et al. 2019).

The value of the identification ICI obtained for the 10 presented CKS candidates was the highest within the pool of 273 traditional medicinal species, indicating that those species have a high cultural relevance and can be considered a priority for conservation and management, when cultural aspects are considered. The ICI index of those species, however, showed a considerable variation in use and cultural importance. The main differences in the ranking were related to two factors, i.e., first, to the ubiquity of the species in the cultural consciousness of the interviewees and second, to the importance for trading purposes. Thus, species with minor commercial importance were also less apparent in the current cultural awareness and vice versa. Seven of the culturally most important medicinal plants in South Tyrol (*Achillea millefolium* agg., *Alchemilla xanthochlora*, *Arnica montana*, *Hypericum perforatum*, *Juniperus communis* subsp. *communis*, *Sambucus nigra*, and *Urtica dioica*) were also reported to be among the most important medicinal plants of other Alpine regions (Christanell et al. 2010, Vitalini et al. 2013, Cornara et al. 2014, Dei Cas et al. 2015). A common biocultural background may explain this similarity because these mountain regions share environmental, historical, and cultural characteristics. Interestingly, the species *Peucedanum ostruthium* was only important in our study area, thus reflecting a certain cultural peculiarity of the region. However, because of its widespread occurrence as a sub-cosmopolitan species, this is not reflected by its phytogeographical character.

Fig. 5. Frequency of occurrence of the cultural keystone species (CKS) candidates as dominant species per habitat. CKS candidates are related to their preferential habitat(s) of occurrence. We used the statistically derived characteristic species combination of EUNIS habitats (for details see Chytrý et al. 2020). Here we count only the occurrence of dominant species. Colors refer to the macro-habitat categories.



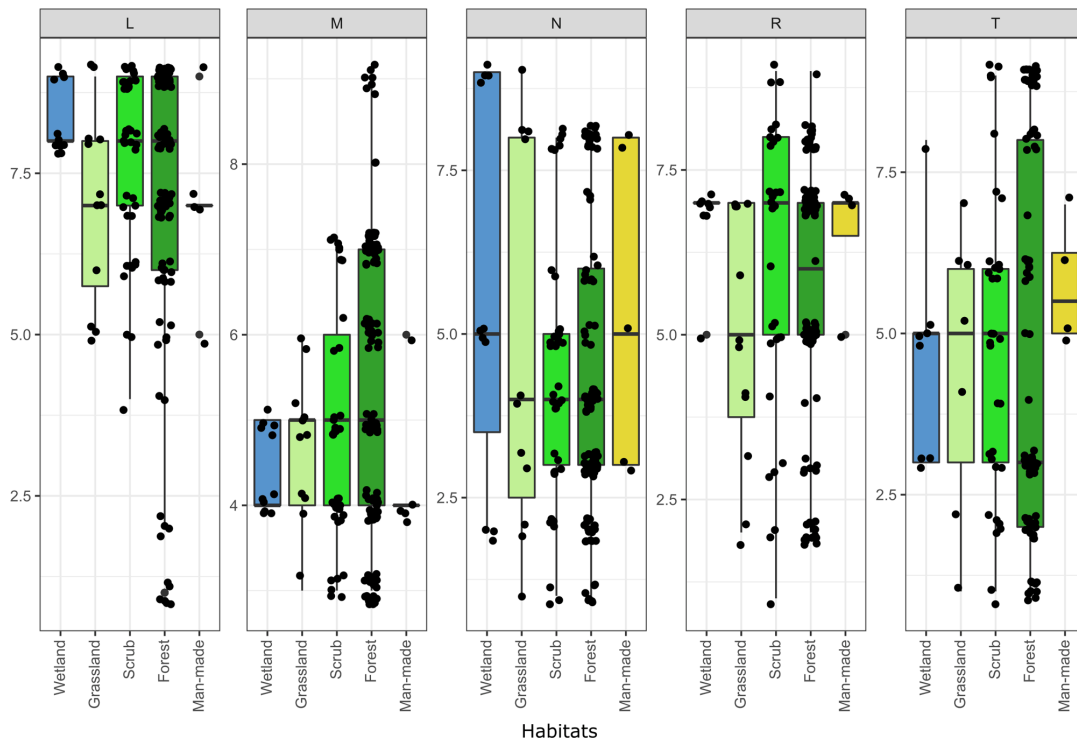
Most of the 10 identified CKS candidates are not threatened and are very common in grasslands (e.g., *Achillea millefolium* agg., *Alchemilla xanthochlora*, *Hypericum perforatum*), scrub vegetation (e.g., *Juniperus communis* subsp. *communis*), and forest habitats (e.g., *Betula pendula*). Thus, their cultural value can promote the conservation, restoration, and sustainable development of traditional habitat mosaics that are under threat of either land abandonment or land-use intensification (Uchida and Ushimaru 2014, Asara et al. 2015, Zerbe 2022). However, in the case of threatened species such as *Arnica montana* further collection in the wild has to be restricted (Schunko et al. 2019). Either this species is cultivated in herb gardens or in habitats such as mountain meadows to stabilize the population. The latter was successfully practiced with a project for the promotion of *Arnica montana* in the NE Bavarian mountains (Germany). The ecosystem restoration of mountain meadows as habitat for *Arnica montana* was linked with its use, which compensates for the costs and thus brought an economic benefit to the local community (Blachnik and Saller 2015). In addition to the use of this species as a medicinal plant, the public was also sensitized to nature conservation and ecosystem restoration, one of the most challenging objectives of the current decade as proclaimed by the UN (2019).

As a key source of medicinal treatment, medicinal plants and associated knowledge are a fundamental pillar of the South Tyrolean culture. Interestingly, the 10 CKS candidates provide

remedies for the most common health problems and therefore can be considered as the first-aid kit that characterizes the culture (Menendez-Baceta et al. 2014). The most frequent therapeutic uses were digestive, respiratory, and integumentary systems that were in line with other ethnobotanical surveys on medicinal plants in Alpine areas (Mattalia et al. 2013, Vitalini et al. 2013, 2015, Cornara et al. 2014). All CKS candidates had the characteristics of a multi-contextual remedy for several disorders highlighting their central role in traditional folk medicine. Moreover, the high medicinal value of the CKS candidates is confirmed by the fact that traditional uses for 8 of the 10 plants have been validated by pharmacological studies (EMA 2021). Furthermore, no or only a few side effects and interactions with other drugs were scientifically attested for those plants. From a pharmaceutical and commercial point of view, today the most important plants are *Hypericum perforatum* (antidepressant and wound-healing properties), *Arnica montana* (analgesic and anti-inflammatory), and *Matricaria chamomilla* (sedative properties on skin and mucous membrane), whereas the other plants are mainly used in folk medicine (Petelka et al. 2020).

Besides their medicinal use, all CKS candidates also covered a wide range of other uses in traditional life underlining their great cultural significance. A strong association between food and medicinal uses was observed. Plants growing on nitrogen-rich sites such as, e.g., *Urtica dioica* and *Alchemilla xanthochlora* were particularly attractive as vegetables. Fruits of *Sambucus nigra* are

Fig. 6. Boxplots of Ellenberg indicator values of cultural keystone species (CKS) candidates occurrences as dominant species per macro-habitat. The boxes show the lower and upper quartile, the horizontal line the median, and the whiskers show the interquartile range. Colors refer to the macro-habitat categories and points are jittered. L = Light; M = Moisture; N = Nutrients; R = Reaction; T = Temperature.



used to prepare jams or juice, and branches of *Juniperus communis* subsp. *communis* are used for smoking traditional ham. The same strong connection applied to the veterinary field, where plants were used to treat the same disorders as they were intended for human beings (Saeidnia et al. 2011, Singh et al. 2011, Vogl et al. 2016).

Besides the medicinal uses, 9 plants were also considered for cosmetic uses. Two of them (*B. pendula* and *U. dioica*) were collected for hair care, while *M. chamomilla* for the skin. Four plant species useful in the cosmetic field, and in two other use categories, also showed a variety of household uses. In organic farming, *Urtica dioica* plays an important role as fertilizer and pest control. Furthermore, *A. montana* was frequently planted in the vicinity of grain fields to drive away demons. The timber of *B. pendula* was used to carve shoes or tie brooms.

Considering the various uses of these plants in the traditional culture, it is not surprising that plants were also given a very high spiritual value or are considered sacred plants, respectively. For example, *H. perforatum* is considered to have mystical qualities, and plants were collected for protection from demons and to drive away evil spirits (Klemow et al. 2011). Similarly, *Sambucus nigra* was used as a protector from all evil (Salamon and Grulova 2015). Birch (*B. pendula*) was applied in fertility rituals. Furthermore, many plants hold great ceremonial importance and were used in the traditional *Kräuterbuschen* (in English: herb bunches,

containing 7, 9, or 30 herbs) for the Assumption of Mary (*A. millefolium*, *A. montana*, *H. perforatum*, *M. chamomilla*, and *P. ostruthium*), the *Corpus Christi* procession (*B. pendula* twigs), or for smoking the Twelfth Night (*P. ostruthium* and *J. communis*; Achmüller 2012). Great respect for the plants was expressed by special harvesting practices and rituals (e.g., taking hats off when walking across *S. nigra*). They also feature in many origin stories and beliefs such as that witches could fly with a broom made of birch twigs, or the burning of *A. montana* to protect farm houses from lightening (Achmüller 2012). In addition, the high cultural importance of the CKS candidates for South Tyroleans was underlined by the great variety of local names (Petelka et al. 2020). All 10 CKS candidates had about 17 and 18 distinct local names each, mostly referring to the use or beliefs in the plants such as the universal remedy of *J. communis* and *P. ostruthium*.

The concept of cultural keystone species in general and the use of indices that aim to measure the cultural importance of a species have been criticized by authors rooted in different disciplines and backgrounds (e.g., Platten and Henfrey 2009, Coe and Gaoue 2020a,b, among others) because of conceptual ambiguities and the subjectivity of the people evaluating the criteria from Garibaldi and; Turner (2004; Table 1). Similar to other authors (Higgs 2005, Quave and Pieroni 2015), we used the concept as a practical tool to link nature and culture in cultural landscapes such as the Alps in combination with a type of consensus approach integrating the expertise of different stakeholders and

Table 2. Characteristics of the identified 10 cultural keystone species (CKS) candidates in South Tyrolian households sorted according to identified cultural influence (ICI) index. Medicinal use: [1] certain infections and parasites; [2] circulatory system; [3] digestive system; [4] genitourinary system; [5] musculoskeletal system and connective tissue; [6] nervous system; [7] respiratory system; [8] skin and subcutaneous tissue; and [9] pregnancy and childbirth. Uses: AL = alimentary use, COSM = cosmetic use, DOM = domestic use; MED = human medicine; REL = religious use, VET = veterinary use; NA = Not assessed. Characterization of the medicinal healing effect based on EMA (2021). For details see Materials and Methods.

Score (ICI rating)	Plant Species	Family	Growth form	Citation frequency	Vernacular names	Plant parts used	Use versatility	Medicinal uses	Side effects or interaction with other drugs	Pharmacological or Phytochemical evidence	Protection status	Red List Status
33	<i>Arnica montana</i> L.	Asteraceae	Herb	13	18	Flower, root	AL; DOM; MED; REL; VET	[1],[4],[6],[7],[8],[9]	Skin necrosis, edematous dermatitis	Positive	Partially protected	LC
33	<i>Hypericum perforatum</i> L.	Hypericaceae	Herb	15	17	Flower, leaf	AL; COSM; MED; REL; VET	[1],[3],[4],[8],[9]	Photosensitization	Positive	Not protected	LC
32	<i>Juniperus communis</i> L. subsp. <i>communis</i>	Cupressaceae	Tree	13	17	Fruit, leaf	AL; COSM; MED; REL; VET	[1],[6],[7],[8],[9]	Pregnancy and kidney inflammation	Positive	Not protected	LC
28	<i>Sambucus nigra</i> L.	Adoxaceae	Tree	13	3	Bark, flower, fruit, leaf, root	AL; DOM; MED; REL; VET	[1],[2],[6],[7],[8],[9]	None recorded	Positive	Not protected	LC
28	<i>Urtica dioica</i> L.	Urticaceae	Herb	15	5	Leaf, root, seed	AL; COSM; MED; REL; VET	[6],[7],[8],[9]	None recorded	Positive	Not protected	LC
27	<i>Achillea millefolium</i> aggr.	Asteraceae	Herb	12	17	Bud, flower; leaf	AL; COSM; DOM; MED; VET	[2],[6],[7],[8]	None recorded	Positive	Not protected	LC
27	<i>Matricaria chamomilla</i> L.	Asteraceae	Herb	13	4	Flower	AL; COSM; MED; REL; VET	[1],[4],[7],[8],[9]	None recorded	Positive	Not protected	LC
25	<i>Betula pendula</i> Roth	Betulaceae	Tree	11	4	Bark, leaf, resin	COSM; MED; VET	[1],[6],[8],[9]	None recorded	Positive	Not protected	LC
25	<i>Peucedanum ostruthium</i> (L.) W.D.J. Koch	Apiaceae	Herb	10	9	Flower, leaf, root	AL; COSM; DOM; MED; REL	[1],[2],[6],[7],[8],[9]	None recorded	NA.	Not protected	LC
24	<i>Alchemilla xanthochlora</i> Rothm.	Rosaceae	Herb	12	18	Flower, leaf, Root	AL; DOM; MED; REL; VET	[1],[3],[7],[8],[9]	None recorded	NA	Not protected	LC

local literature. We are aware that a limitation of our study is represented by the fact that it is not hypothesis-testing based. A considerably higher number and diversity of stakeholders in future studies will deal better with possible limitations of subjectivity and potential biases of this study that can open the opportunity to use robust statistical methods (e.g., Coe and Gaoue 2020b), than our explorative approach.

CONCLUSIONS

We found the first evidence that traditional medicinal plants are ideal to be potential CKSs. The development of innovative approaches to positively link biodiversity conservation and the strengthening of the cultural identity is a promising area for future participatory research including and valorizing the existing knowledge and different practices of the local community around traditional medicinal plants and their habitats. Despite the general trend of habitat loss and cultural erosion, the last decades have seen renewed social and scientific interest in traditional medicinal plants and associated knowledge. For example, many mountain farmers confronted with the structural changes in mountain agriculture have switched their production to herb cultivation. But also, several gastronomies and hotel businesses have recognized the potential of traditional plants and knowledge

and offer seasonal dishes and wellness programs based on traditional plants and practices. At the same time, many new books on traditional medicinal plants have been published in the last decades throughout the Alps. The renewed interest and commercial use of herbal plants (e.g., Pieroni and Giusti 2009, Abbet et al. 2014, Pinela et al. 2017, Schunko et al. 2019, Petelka et al. 2020) seem to offer numerous positive effects on the economic and ecological sustainability of South Tyrol and other parts of the European Alps. These effects comprise (i) the diversification of agricultural production, (ii) the maintenance of the rural economy, (iii) the establishment of local value chains, (iv) the preservation of traditional land-use types through extensive and ecologically oriented farming systems, (v) an important habitat for other animals (e.g., insects), and (vi) the preservation and revitalization of local identities, with a likely effect on biodiversity conservation. In this study, we suggest the CKS concept adapted to traditional medicinal plants offers a synergy between local culture and plant species, and thus might facilitate nature conservation efforts by rooting them in the local communities.

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Data Availability:

The data that support the findings of this study are openly available in the appendices.

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APPENDIX 1. Table of occurrences per (macro-)habitat of the South Tyrolian Cultural Keystone Species (CKS) candidates. Counts are sums of sub-habitats (not shown) occurrences as diagnostic, constant, and dominant species; habitats' codes follow Chytrý et al. (2020).

Code	Habitat name	No. of CKS candidates hosted
Wetlands		
Q1	Raised and blanket bogs	12
Q2	Valley mires, poor fens and transition mires	26
Q4	Base-rich fens and calcareous spring mires	44
Q5	Helophyte beds	6
Total		88
Grasslands and lands dominated by forbs, mosses or lichens		
R1	Grasslands and lands dominated by forbs, mosses or	145
R2	Mesic grasslands	82
R3	Seasonally wet and wet grasslands	70
R4	Alpine and subalpine grasslands	47
R5	Woodland fringes and clearings and tall forb stands	88
Total		432
Heathlands, scrub and tundra		
S2	Arctic, alpine and subalpine scrub	84
S3	Temperate and Mediterranean montane scrub	141
S4	Temperate heathland	17
S9	Riverine and fen scrub	26
Total		268
Forests and other wooded land		
T1	Broadleaved deciduous forests	353
T3	Coniferous forests	285
Total		638
Vegetated man-made habitats		
V1	Arable land and market gardens	74
V2	Cultivated areas of gardens and parks	1
V3	Artificial grasslands and herb-dominated habitats	62
Total		137

Appendix 2. Boxplots of Ellenberg indicator values of cultural keystone species (CKS) candidate occurrences per macro-habitat (all occurrences). The boxes show the lower and upper quartile, the horizontal line the median, the whiskers the interquartile range. Colors refer to macro-habitat categories and points are jittered. L = Light; M = Moisture; N = Nutrients; R = Reaction; T = Temperature.

