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ORCHARD MEADOWS IN SOUTH TYROL

SPATIO-TEMPORAL DEVELOPMENT AND AGRO-ECOLOGICAL EVALUATION

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Alexander Schönafinger

Matrikelnummer: 01517968

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BETREUT VON

Erich Tasser

Lukas Egarter Vigl

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ABSTRACT

Orchard meadows, a special agroforestry system with high-stemmed fruit trees scattered in meadows, pastures or arable land, are traditional elements in the cultural landscape of Central Europe. They have been decreasing by -75% since the middle of the 20th century, apparently due to agricultural intensification, urbanization, or land abandonment. In this study, the historical and current distribution of orchard meadows was mapped for South Tyrol (North Italy), followed by a spatio-temporal analysis of changes since the 1950s. Furthermore, a field study was conducted, including interviews and onsite surveys in selected orchards throughout South Tyrol to understand temporal changes in fruit composition and agricultural management since the 1990s.

The orchard meadow area in South Tyrol has decreased by more than 6,000ha (-95%) over the past 75 years, which shows one of the strongest declines in Central Europe. A loss occurred at all elevations, slopes, and expositions and was highest at lower elevations (-5,155ha), shallow slopes (-4,313ha), and expositions towards the south (-5,035ha). The loss of orchard meadows was mainly driven by agricultural intensification (69%), urbanization (23%), and land abandonment (6%), where former orchard meadows were mainly converted to modern orchards (56%), built-up areas (14%), infrastructure (8%), intensively managed grasslands (8%), and forests (6%). The tree density within orchard meadows has decreased from 56 ind. ha^{-1} to 45 ind. ha^{-1}, despite the strong increase in tree density within intensive apple plantations in South Tyrol (up to 10,000 ind. ha^{-1}). The analysis of fruit composition showed an increase in diversity of fruit species. Unlike the 1990s, khakis, pomegranates, and olives in particular were newly added to the fruit assortment. In the meantime, orchard meadows have been planted more frequently in home gardens and an increased use as recreational space can be observed. Furthermore, remaining orchard meadows appeared to be better maintained, the age structure of the trees was more diverse, but the field crop diversity was more often species-poor. The interest in orchard meadow cultivation and fruit diversity has apparently increased. Moreover, orchard meadows are important landscape elements, providing high natural and cultural values. However, this agroforestry system is highly threatened to end up in South Tyrol due to the ongoing intensification of agricultural practices and the lack of profitability. The current distribution of traditional orchards should therefore be monitored in upcoming agricultural censuses, in order to identify suitable conservation strategies and to promote their spreading in the cultural landscape of South Tyrol.

OUTLINE

1. INTRODUCTION

Agroforestry has a long history in agricultural practices throughout Europe. Probably the oldest form dates back to the Neolithic period (wood pastures; Nerlich *et al.* 2013). Other old agroforestry systems are, for example, "*Dehases*" in Spain or "*Montados*" in Portugal, which are oak woodlands in combination with extensively used pastures and date back to 4,500 B.C. (Nair *et al.* 2008). The combination of growing trees and cultivating crops or fodder within the same area was since then applied in various traditional agricultural systems. In Europe, the most common types are silvoarable (trees with arable or horticultural crops), silvopastoral (trees with forage and livestock production), and orchard intercropping systems (fruit tree cultivation on arable land or grassland), but also riparian buffer strips, and hedgerows/windbreaks (Plieninger *et al.* 2012, Nerlich *et al.* 2013). Orchard meadows are a common type of orchard intercropping system in temperate Europe (Forejt & Syrbe 2019). They are characterized by high-stemmed (1.6 to 1.8m) fruit trees, scattered throughout meadows, pastures, or arable land (Herzog 1998). The tree density usually varies between 20 and 100 individuals per hectare (Herzog 1998, Nerlich *et al.* 2013, Plieninger *et al.* 2015b). The planted fruit trees are an assemble of various species and varieties. In Central Europe, they are typically poaceous and stone fruit trees (apples, pears, plums, apricots, cherries, etc.), but occasionally also nut trees (mainly walnuts or chestnuts) can be interspersed (Weller 2014, Plieninger *et al.* 2015b, Forejt & Syrbe 2019). Furthermore, the use of pesticides is not intended in orchard meadows, since the cultivated varieties are usually very robust and well adapted to local conditions (Kornprobst 1994, Blume 2010, Zehnder & Weller 2016). The terminology of orchard meadows became only relevant since the intensification of fruit production, beginning in the early 20th century. Thus, the German designation "*Obstbau in Streulage*" was firstly introduced by Knauer (1940), leading to the term "*Streuobstwiese*" (Weller 2014). The German designation is translated to "*orchard meadow*" or, in some cases, also to "*traditional orchard*". Other European countries, for example, translate orchard meadow to "*pré-verger*" (French), "*luční sad*" (Czech), or "*sodová lúka*" (Slovak; Forejt & Syrbe 2019).

Traditional agroforestry systems, especially orchard meadows, provide habitat for a great number of flora and fauna. They include ecological niches for representatives of both forest and open landscape communities, but also for specialized species that rely on such heterogeneous structures with a diverse mosaic of small biotopes (Heller 2004, Zehnder & Weller 2016, Guariento *et al.* 2020). Furthermore, orchard meadows are often combined with apiculture, because they are rarely affected by pesticides, unlike intensively managed orchards (Herzog 1998, Guariento *et al.* 2020). In addition to their importance for biodiversity, orchard meadows also provide numerous ecosystem services (Nerlich *et al.*

2013, Plieninger *et al.* 2013, Fagerholm *et al.* 2016). In traditional agroforestry systems, rich natural and socio-cultural values are strongly linked (Rolo *et al.* 2020) and they are thus significantly contributing to human well-being. However, the socio-economic development since the twentieth century resulted in a loss of landscape heterogeneity and in landscape fragmentation (Plieninger *et al.* 2015b). These changes have had a negative impact on biodiversity (Weller 2014, Zerbe 2019) and other ecosystem services (Herzog 1998, López-Sánchez *et al.* 2020), for instance, leading to a degradation of soil and water (Foley *et al.* 2005).

Although (wild) fruit trees were already evidently part of European cultural land in 600 B.C. (Schramayr 2001), most of the fruit varieties and the agricultural practices of fruit cultivation and reproduction today originated in the Persian, Egyptian, and Indian Empires, were adapted by Ancient Greece and the Roman Empire, and were transferred by the Romans to Central Europe (Herzog 1998, Oberhofer 2007c, Weller 2014). In later centuries, orchards were adopted mainly by Carolingian estates and monasteries, which significantly contributed to their development. In the 17th century, orchards gained importance for fruit markets and became therefor increasingly planted on open land. In the 18th and 19th centuries, they finally became highly present in Central Europe, despite strong declines due to devastations during the Thirty Years War. In this period, authorities strongly contributed to the revitalization of orchard meadows by creating nurseries and publishing regulations, for instance, linking the permissions of citizenship and marriage to the obligation of planting fruit trees. Furthermore, damaging or destructing fruit trees was sanctioned with severe punishments (Weller 2014). The motivation of the authorities to establish orchards in this period was primarily economic and has led to traditional and modern orchard cultivation, which shape the landscape of Central Europe to this day (Herzog 1998, Weller 2014). The early forms of traditional orchards were mostly silvoarable (combination with cropland; Herzog 1998, Eichhorn *et al.* 2006, Weller 2014). At the beginning of the twentieth century, they became more frequently combined with grasslands (silvopastoral), due to the economic shift towards dairy farming (Weller 2014). Fruit varieties within orchard meadows moreover experienced a standardization due to exchanges, trading, and variety recommendations throughout Central Europe during the twentieth century (Schramayr 2001). This has led to an increasing lack of importance for regional and local varieties (Herzog 1998, Plieninger *et al.* 2013). However, other aspects are still regionally influenced, such as the composition of fruit species, the structure, and the size of a traditional orchard (Schramayr 2001).

In Central Europe, orchard meadows reached their peak in the 1930s, but declined since then, due to their decreasing profitability, the intensification of agricultural practices, urbanization and land abandonment (Eichhorn *et al.* 2006, Weller 2014, Plieninger *et al.*

2015b). The decline reaches from -15% in Bohemia, Czech Republic (since the mid-1950s; Forejt & Syrbe 2019), to -94% in Belgium (1944-1976; Weller 2014). Similar forms of fruit intercropping agroforestry systems in Europe experienced also significant losses, for instance, cider-orchards in Great Britain (-56 %; Burrough *et al.* 2010).

The history of fruit cultivation in South Tyrol thus indicates a similar development of orchard meadows as in Central Europe. The Northern Italian region of South Tyrol (Südtirol, Alto Adige) is influenced by different Central European aspects, since the County of Tyrol was governed by the Counts of Tyrol and the Austrian Empire until 1918 (Pinzer 1995, Haidacher 1995). The predominant types of agroforestry are larch meadows (Fontana *et al.* 2014, Nascimbene *et al.* 2014, Nagler *et al.* 2015) and chestnut groves (Radtke *et al.* 2013, Loos 2020), but also orchard meadows exist in the cultural landscape of South Tyrol (Oberrauch 2001, Guariento *et al.* 2020). However, fruit cultivation gained importance only after 1820, due to the famine and grain shortage induced by the Napoleonic War (Oberhofer 2007b). At first, croplands were increasingly combined with fruit trees to mainly improve self-sufficiency, but with the construction of the railway between Bozen (Italy) and Innsbruck (Austria) and the connection to the international train network in 1867, new opportunities have been created for South Tyrol's fruit export (Oberhofer 2007d). At the beginning of the twentieth century, the first approaches to commercial fruit cultivation were established in the form of high-stemmed fruit trees combined with grasslands for fodder production (orchard meadow) were established. Nonetheless, the production of fodder and crops still remained more economically important at first. Starting in the 1920s, the cultivation of fruit was becoming more significant in the South Tyrolean part (from the end of World War 1 as an Italian province) and also many vineyards were changed into orchards. Furthermore, also the tree density gradually increased and shortly after, the fruit and fodder production was completely separated. This was further encouraged due to the use of pesticides, which was extremely dangerous to cattle. The intensification of fruit production in South Tyrol (mainly apples) was finally boosted by the cultivation in form of the "free palmette system" (based on a fruit cultivation method from Ferrara, Italy) in the 1970s (Oberhofer 2007e) and increased export demands as a consequence of the construction of the Brenner highway in 1972 (Oberrauch 1997).

However, how all these historical developments have affected the historical and current distribution of orchards in South Tyrol is largely unknown. This may be due to agricultural statistic assessments, which mainly focus on intensive agricultural systems, but also due to many studies, which do not include South Tyrol in the Central European context (e.g.: Herzog 1998, Nerlich *et al.* 2013, Forejt & Syrbe 2019).

1.1. Hypothesis and objectives

Given the strong decrease of orchard meadows in Central Europe due to agricultural intensification, urbanization, and land abandonment, a decline in orchard meadow area is also expected to have occurred in South Tyrol since the middle of the twentieth century. Therefore, this study aims to analyse the distribution of orchard meadows in the mid-1950s and today, in order to:

- Assess the dimension of spatio-temporal changes in the orchard meadows.
- Identify the main drivers of orchard meadow transformation.

Furthermore, a standardization of fruit varieties has occurred and agricultural intensification has also influenced the management of traditional orchards. A change in fruit composition and agricultural management of orchard meadows thus can also be expected for orchard meadows in South Tyrol. Therefore, data on the current status are collected throughout a field survey and are compared to similar data, collected in the 1990s (Oberrauch 1997), in order to:

- Assess the alteration in fruit composition at the levels of species and variety.
- Determine the changes in central aspects of agricultural management.

2. MATERIAL AND METHODS

In this study, a mapping approach and a field survey were conducted to analyse the spatio-temporal development and some agro-ecological changes of orchard meadows in South Tyrol (Fig. S1). Orchard meadows were defined as grassland with at least three tall fruit trees, which are scattered in a regular or irregular pattern and show a minimum distance of 5m between the edges of the canopy (BUND Landesverband Niedersachsen e.V. 2016, Plieninger *et al.* 2012). Furthermore, they had a size of at least 0.1 hectares (ha) and a tree density between 20-100 individuals (ind.) ha^{-1} (Plieninger *et al.* 2015b).

2.1. Study area

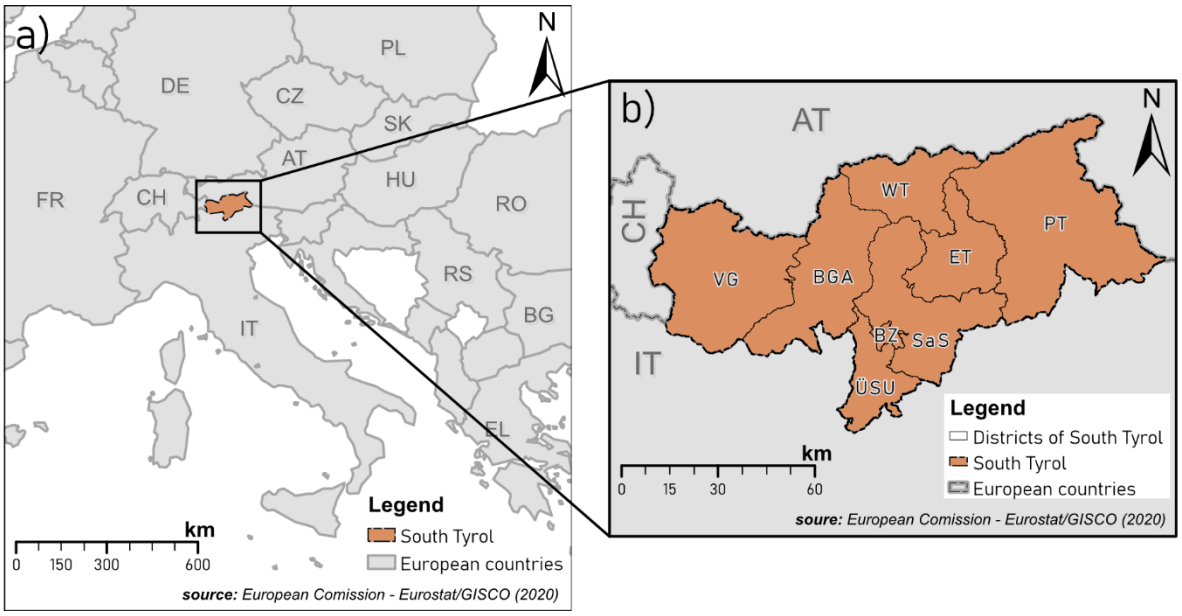

Figure 1: *The study area South Tyrol is the Northern-most region of Italy (IT) and is adjacent to Switzerland (CH) and Austria (AT)* ***[a]****. It is further divided into eight districts* ***[b]****: Bozen (BZ), Burggrafenamt (BGA), Eisacktal (ET), Pustertal (PT), Salten-Schlern (SaS), Überetsch-Südtiroler Unterland (ÜSU), Vinschgau (VG), and Wipptal (WT).*

This study focused on orchard meadows within the Autonomous Province of South Tyrol, the most northern province of Italy (Fig. 1a). South Tyrol shares its borders with Switzerland in the west, and with Austria in the north and east and is further divided into eight districts (Fig. 1b) and 116 municipalities.

Its total area comprises almost 740,000ha, the landscape shows a heterogeneous elevation profile between 180 and 3,900 meters above sea level (m a.s.l.; Copernicus 2016), and it is located in a temperate continental climate zone (Hilpold *et al.* 2020b). The landscape consists of forests (50%), agricultural land (37%), unproductive areas (10%) and

settlements (3%). The agricultural land-use/land-cover includes pastures (59%), meadows (27%), orchards (8%), vineyards (3%), and crops (3%; Anderle *et al.* 2022). Only in the Bozen and Überetsch-Südtiroler Unterland districts, agriculture is mainly composed of orchards, vineyards, and permanent meadows and pastures. In all other districts permanent meadows and pastures are clearly dominant (ASTAT 2013).

2.2. Mapping

The spatio-temporal analysis was designed to identify the historical and recent distribution of orchard meadows in South Tyrol. The applied approach was based on the identification of orchard meadows by using digital orthophotos, similar to Plieninger *et al.* (2015b). For the historical distribution, the orthophoto taken in 1954-56 (resolution: 1.5x1.5m; colour spectrum: black-white) was used and therefore refers to the mid-1950s, while the recent distribution was determined by using the latest available orthophoto (resolution: 0.2x0.2m; colour spectrum: coloured), taken in 2020 (Amt für Landesplanung und Kartografie 2023). An individual polygon file was generated for both timesteps, by manually digitizing orchard meadows (working scale: 1:2,500). The borders were drawn at visible field margins or around the outermost trees, depending on the distribution of trees within a field (Fig. S2). Furthermore, the trees within the orchard meadows were also mapped as points for each timestep (as a consequence of the high number of orchards, the historical timestep only includes trees within the district of Vinschgau). After the mapping of historical and recent orchard meadows, adjacent orchard meadows were merged to get the largest contiguous orchard meadow areas. The tree density of the current orchard meadows was calculated by referring to the generated tree datasets. For the mid-1950s, the tree density was calculated only for Vinschgau.

2.2.1. Topographical changes

A temporal comparison of spatial and topographic parameters allowed a deeper insight into the development of orchard meadows in South Tyrol. Therefore, the distribution of the orchard meadows were analysed in the context of elevation, slope, and exposition, which were derived from the current digital elevation model (DEM) of South Tyrol (Copernicus 2016). Subsequently, the data of both datasets were evaluated by deriving the number of orchard meadows and by calculating the total area for each time step. The relative total area was calculated as the proportion of orchard meadow area within the used agricultural land (Tab. 1) and evaluated by classifying the topographic variables into subgroups (Tab. S1). Furthermore, the average area, average tree density, and distribution within the elevation, slope, and exposition classes were calculated and spatial and temporal

differences were statistically tested, using the Levene's test (Levene 1960) to test homoscedasticity (package psych v2.2.9; Revelle 2022), and the Welch's t-test (heterogenous variances; Welch 1947) or Student's t-test (homogenous variances; Student 1908) to test the means of two independent samples.

Table 1: *Used agricultural land (UAA: arable land, grassland, permanent crops) of South Tyrol and its districts in 1954 and 2010 (ASTAT 2023b, ISTAT 2023).*

	UAA [ha] in:		
	1954	**2010**	**Change [%]**
Bozen	1,630	1,747	7.2
Burggrafenamt	15,172	15,460	1.9
Eisacktal	10,878	9,505	-12.6
Pustertal	23,053	22,063	-4.3
Salten-Schlern	14,071	15,269	8.5
Überetsch-Südtiroler Unterland	13,344	12,769	-4.3
Vinschgau	12,130	11,288	-6.9
Wipptal	6,460	5,661	-12.4
South Tyrol	96,738	93,762	-3.1

2.2.2. Land-use/land-cover (LULC) change

To further investigate the development of orchard meadows since the mid-1950s, the change in LULC within their historical distribution was analysed. Therefore, the current high resolution LULC dataset (Anderle *et al.* 2022) was updated with the current distribution of the mapped orchard meadows. This LULC dataset has a pixel size of 5x5m and is composed of 59 different LULC types, which were summarized within this study to twelve main groups (Tab. S2). To investigate only areas of the orchard fields of the 1950s, these areas were extracted from the complemented LULC dataset. Finally, the data were evaluated by calculating the total area of each LULC group for South Tyrol and its districts.

2.3. Field survey

In summer 2022, 61 orchard fields in South Tyrol were visited as part of an orchard meadow championship, organized by the "Initiative Baumgart" (Initiative Baumgart 2021). These sites were selected by self-registration of the owners to the championship and were therefore unevenly distributed between the districts of South Tyrol. They may also not represent the entirety of orchard meadows in South Tyrol, due to the owners self-registration and the possibility of exceptionally well-groomed orchards. The visited fields included orchard meadows younger than five years old, which were distinguished as "newly established" and were located mainly in Vinschgau (Tab. S3).

Table 2: *Investigated topics throughout the field survey in summer 2022.*

Criteria	Indicators	Description
Fruit varieties	Primarily modern varieties Partially modern/old varieties Primarily old varieties	
Fruit diversity	One fruit species Multiple fruit species	
Field crop diversity	Species-poor Species-rich	less than 35 species more than 35 species
Field crop management	No vegetation Meadow without grass-usage Meadow/pasture/cropland	
Fruit management	Not harvested Harvested without processing Harvested with (various) processing Harvested with economic interest	 juices, marmalades, etc. farmer's market, cooperative, gastronomy, etc.
Recreation potential	Not implemented Implemented	 seating facilities, playground, etc.
Grooming	No/little grooming Regular grooming	
Rejuvenation	Not rejuvenated Rejuvenated Newly established	no young trees at least one young/old tree no old trees

Within this survey, several criteria were investigated conducting on-site inspections and interviews with all owners (Tab. 2). The interviews mainly aimed to determine indicators on fruit varieties, field crop management, and fruit management. In addition, owners were also interviewed about the exact fruit varieties, which were grown in their orchard meadows. Unknown varieties were designated as "indeterminate" (indet.). All other criteria were investigated throughout the on-site inspection. The identification of the indicators on grooming was mainly based on correct pruning of the fruit trees and its effect on the canopy shape (see e.g. Pardon & Reubens 2019).

2.3.1. Fruit composition

Orchard meadows are typically rich in fruit species and varieties. Hence, this study also focused on fruit trees and their compositional change within orchard meadows in South Tyrol. On this basis, fruit varieties collected throughout a survey conducted in 1994 (Oberrauch 1997) were compared with the data collected throughout the survey conducted in this study (Tab. S4). The survey in the 1990s includes an investigation on fruit varieties in all orchard meadows (number of fields: 234) of three municipalities in South Tyrol: Kiens (Pustertal), Feldthurns, and Schluderns (Vinschgau).

The temporal analysis of the fruit varieties followed a binary approach, in which each variety was assigned as present or not present for each survey site. The data were then compared by the number of varieties for each fruit species and the frequency of the fruit species. Moreover, the frequency of apple and pear varieties was evaluated in more detail, due to their high prominence within orchards in South Tyrol and Central Europe (Hehenberger 1998, Hutter & Wetzel 2004, Oberhofer 2007a, Stehr *et al.* 2011, Zehnder & Weller 2016, Handlechner & Schmidthaler 2019).

2.3.2. Agricultural management

This study also aimed to investigate the effects of orchard meadow development on agricultural management. Data collected through the field survey in the summer of 2022 were thereby compared to similar data, investigated in a survey conducted in 1994 (Oberrauch 1997; Tab. S4). Both datasets include information on the field crop management (meadow, pasture, vegetables) or recreation use, type of business (agricultural, private, public orchard), age of tree stock (not rejuvenated, rejuvenated, newly established), location (near (farm) house, remoted), field crop diversity (no vegetation, species-poor, species-rich), and grooming (no/little or regular grooming). For the field crop management criterion, multiple indicators could have been assigned to an orchard meadow. For all other criteria, only one indicator at a time was assigned. Similarly to the analysis on fruit tree species, the temporal analysis of agricultural management also followed a binary approach, where the frequency of each indicator was evaluated.

2.4. Data handling

The calculations and modifications of the map datasets were carried out with ArcMap v10.7 (ESRI 2019). The evaluation of raw data and result visualization were calculated in RStudio v2022.12.0.353 (Posit team 2022) with R v4.2.2 (R Core Team 2022; Tab. S5).

3. RESULTS

3.1. Spatio-temporal development of orchard meadows

Over the past 75 years, the number of contiguous orchard meadows in South Tyrol decreased by approximately -3,000 (-78%, Tab. 3). A decrease was observed throughout all districts, whereat the highest decrease occurred in Überetsch-Südtiroler Unterland and Bozen (-96% respectively) and the lowest in Vinschgau (-48%).

Table 3: *Historical and recent distribution of orchard meadows (OM) within South Tyrol and its districts.*

	Number of OM in:		Area [ha] of OM in:		
	1954-56	2020	1954-56	2020	Change [%]
Bozen	113	5	320.2	1.6	-99.5
Burggrafenamt	917	186	1,964.1	65.5	-96.7
Eisacktal	624	134	497.4	41.8	-91.6
Pustertal	518	149	250.2	52.1	-79.2
Salten-Schlern	395	97	211.3	35.6	-83.1
Überetsch-Südtiroler Unterland	869	35	1,637.5	10.2	-99.4
Vinschgau	431	226	1,455.8	84.7	-94.2
Wipptal	49	17	28.5	5.0	-82.7
South Tyrol	3,890	849	6,364.9	296.4	-95.3

In the 1950s, the total area of orchard meadows covered 6,365ha. Over the past 75 years, it decreased by -95% (-6,069ha), which today leaves only 296ha (Tab. 3, Fig. 3a). The highest losses suffered Bozen (-99.5%), and Überetsch-Südtiroler Unterland (-99.4%); the smallest decrease was observed in Wipptal (-82.7%) and Pustertal (-79.2%). Furthermore, the biggest orchard meadow still covered approximately 340ha in the 1950s. In 2020 however, the largest contiguous orchard meadow cover decreased to only 3ha (Fig. S3). Historical orchard meadows represented nearly 7% of UAA, while today, they represented only 0.3% (Tab. S6). A decrease in proportion was observed in all districts (Fig. 2). The biggest changes showed Bozen, which decreased from 19 to 0.1%. The smallest occurred in Wipptal, which decreased from 0.4 to 0.1% (Tab. S6).

The average area of orchard meadows decreased from 0.54 ± 0.38ha to 0.25 ± 0.14ha (Welch's t-test: $t_{4003} = 39.7$, $p < 0.001$; Fig. S8a). This development was observed in all districts, where Bozen, Überetsch-Südtiroler Unterland, and Burggrafenamt showed the highest, Salten-Schlern and Pustertal the smallest changes (Fig. S9).

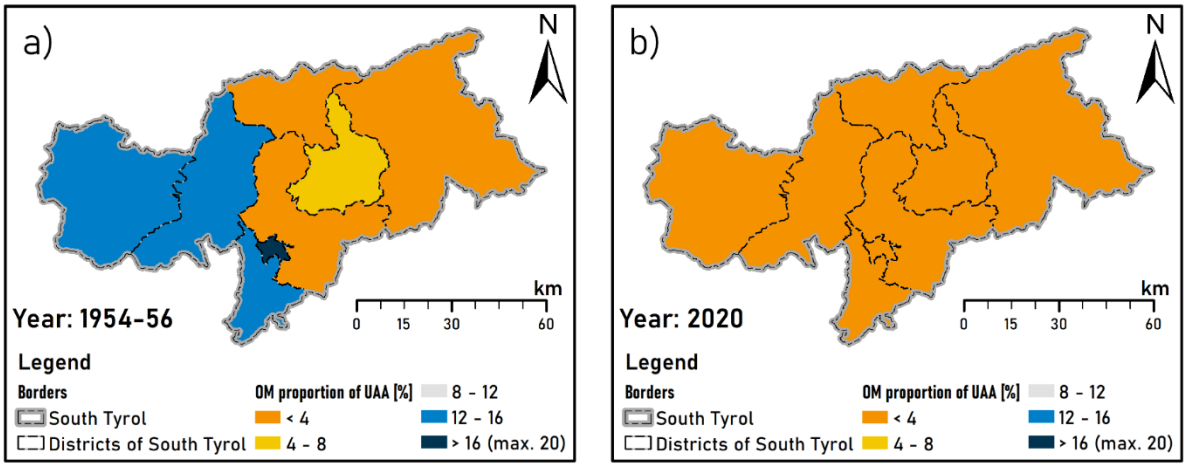

Figure 2: *Historical **[a]** and recent **[b]** distribution of orchard meadows (OM) as proportion of used agricultural area (UAA) within South Tyrol's districts.*

In addition, a change in relative distribution was observed along the elevation gradient. In the 1950s, 82% of the orchard meadow areas were located below 800m a.s.l., while today's orchard meadows were mostly observed between 800 and 1,200m a.s.l. with 52% (Fig. 3b, Tab. S7). Thus, orchard meadows were averagely situated at 716 ± 417m a.s.l. in the 1950s and at 961 ± 249m a.s.l. in 2020 (Welch's t-test: $t_{1569} = -26$, $p < 0.001$; Fig. S8b). However, in Salten-Schlern the mean elevation remained nearly the same, which means that a uniform decrease occurred at all elevations. In Wipptal even a decrease occurred, indicating an increased reduction at higher elevations (Fig. S11). Furthermore, the total area showed a decrease in all elevation classes. The highest decrease was observed in the colline belt between 0-800m a.s.l. with a reduction of -5,155ha (-98.8%). The submontane belt (800-1,200m a.s.l.) showed a decrease of -720ha (-82.3%) and the montane belt (1,200-1,800m a.s.l.) of -193ha (-71.2%) (Tab. S7a, Fig. S5).

The relative distribution categorized by slope showed that in 1954-56, 69% of the orchard meadow areas were situated at surfaces with gentle inclination (1-11°). Today, however, they were observed to be more equally distributed at steep (21-31°; 34%), moderate (11-21°; 31%), and gentle (25%) inclinations (Fig. 3c, Tab. S7, Fig. S6). The decline gradually decreased at incremented class, thus showing the smallest decrease at classes with the highest slope (Tab. S7b, Fig. S6). On average, orchard meadows were found on steeper slopes (1950s: 10.5 ± 11.7°, today: 17.7 ± 11.4°; Welch's t-test: $t_{1191} = -13.9$, $p < 0.001$; Fig. S8d). This development was observed in all districts, whereat orchards in Überetsch-Südtiroler Unterland, Burggrafenamt, and Bozen showed the highest changes and Salten-Schlern the smallest (Fig. S12).

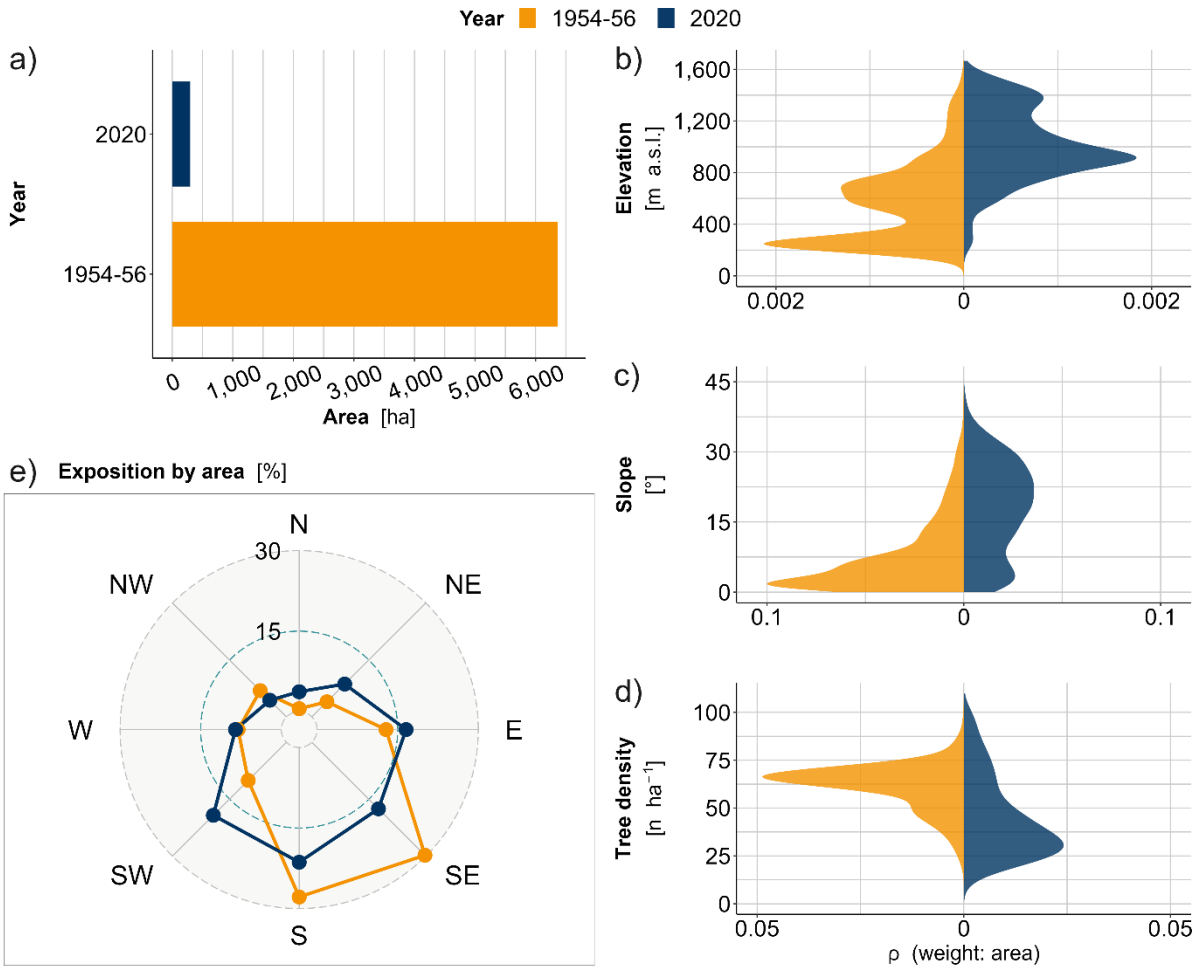

Figure 3: *Area distribution of orchard meadows **[a]** and relative distribution by elevation **[b]**, slope **[c]**, tree density (only for the district of Vinschgau) **[d]**, and exposition **[e]**.*

The tree density of the orchard meadows in Vinschgau decreased from 56 ± 19 ind. ha^{-1} to 45 ± 23 ind. ha^{-1} (Welch's t-test: $t_{374} = 3.5$, $p < 0{,}001$) since the middle of the 20th century (Fig. 3d, Fig. S8b). In South Tyrol, an average tree density of 46 ± 22 ind. ha^{-1} was observed in today's orchard meadows and the smallest tree density showed Burggrafenamt, Pustertal and Wipptal, the highest Bozen and Überetsch-Südtiroler Unterland (Fig. S10).

The relative distribution of the orchard meadow area by exposition (Tab. S1d) decreased towards the southeast (SE; -12.3%), south (S; -6.5%), and northwest (NW; -2.5%). Orchard meadows exposed towards the west (W) increased only by 0.5%. However, the highest increase was observed towards the southwest (SW) with 9.2% (Fig. 3e). Categorized by exposition only towards north (270-90°) or south (90-270°; Tab. S1c), the dimension of orchard meadow loss was nearly the same (south: -96%, north: -94%; Tab. S7, Fig. S7). However, in the 1990s still 5,035ha (79%) of orchard meadows were exposed towards the south, while today, there were only 216ha (73%).

3.2. Land-use/land-cover (LULC) change

The loss of historical orchard meadow areas in South Tyrol (Fig. 4) was primarily caused by land conversion into modern orchards with more compact fruit trees (56%). Only 33ha of orchard meadows (0.5%) were preserved over the past 75 years. In addition to orchards, LULC was also converted into build-up areas (14%), infrastructure (8%), grassland (8%), and forests (6%; Tab. S8). The change to intensive agricultural LULC (arable land, grassland, orchards, and vineyards) occurred in more than two thirds (69%) of the former orchard meadow areas, which represents nearly 5% of the UAA in 2010 (Tab. 1). The next largest LULC change occurred due to urbanization (23%; built-up areas, infrastructure) and land abandonment (6%; forests). LULCs with fewer than 0.1% portions (bare rocks and rock debris, wetlands, Tab. S8) could possibly be excluded due to discrepancies with respect to the mapping process.

LULC changes varied between the districts of South Tyrol. Orchard meadows were mostly converted to orchards in Überetsch-Südtiroler Unterland (68%), Vinschgau (66%), Burggrafenamt (61%), and Bozen (57%). In Eisacktal, they were primarily changed into grassland and build-up area and in Pustertal, Salten-Schlern, and Wipptal into grassland and forests (Tab. S8).

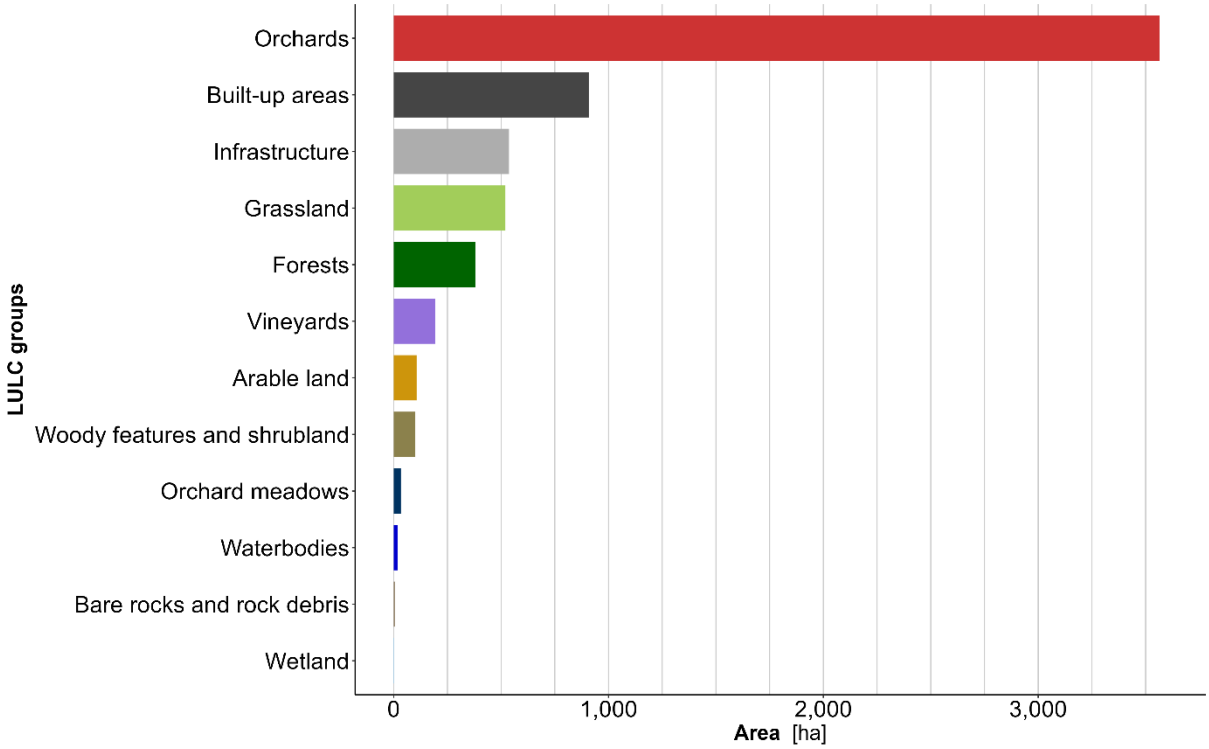

Figure 4: *Land-use/land-cover (LULC) change of orchard meadows in South Tyrol since 1954-56.*

3.3. Changes in fruit composition

The comparison of surveyed orchard meadows in 1994 and 2022 showed differences in fruit species and their respective number of determined varieties (Fig. 5). In today's survey, 19 different fruit species were found in all visited sites, while in 1994 only twelve were observed (Tab. S9). The twelve fruit species found in the 1990s survey also occurred in today's visited orchard meadows. The seven additional species found in today's survey were medlars, almonds, hazelnuts, khakis, mulberries, pomegranates, and olives. However, it is unclear whether these fruits also occurred in orchard meadows in 1994, but most likely khakis, pomegranates, and olives appeared in South Tyrolean orchard meadows only after the 1990s (personal communication: Oberrauch 2022).

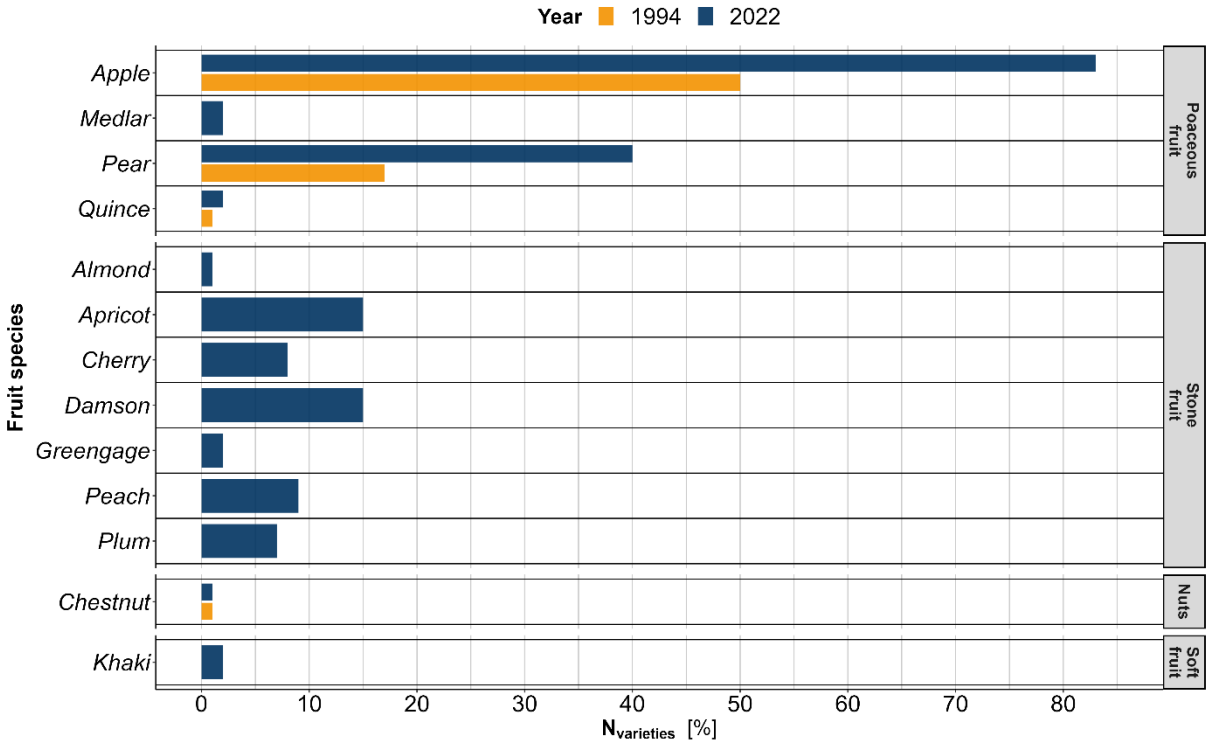

Figure 5: *Fruit species by number of determined varieties in percent within orchard meadows surveyed in 1994 (Oberrauch 1997) and 2022. Fruit species are additionally categorized by fruit types.*

In 1994, only varieties for apples, pears, quinces, and chestnuts had been determined. In 2022, the varieties of medlars, almonds, apricots, cherries, damsons, greengages, peaches, plums, and khakis were also determined at the visited sites. The chestnuts were represented in both years by the variety *Edelkastanie*. All other fruit species showed an increase in determined varieties over the past 28 years. In both surveys, apples had the highest number of varieties, followed by pears (Fig. 5). In both years, some varieties could

not be determined (Tab. S9) at many survey sites. These undetermined varieties could potentially include a not neglectable number of varieties.

On average, apple varieties were the most frequent within orchard meadows both in 1994 (2 ± 22 varieties) and 2022 (4 ± 5 varieties). Moreover, the average number of pears within an orchard meadow was 1 ± 16 varieties in 1994, and 2 ± 5 varieties in 2022.

3.3.1. Apples

Within the surveyed orchard meadows, 50 apple varieties were found in 1994 and 83 in 2022 (Tab. S9); 25 of these varieties were found in both years. In 2022, *Kalterer Böhmer*, *Gravensteiner*, *Canada Renette*, and *Golden Delicious* occurred more often on orchard meadows. On the other hand, *Golden Delicious* (54%) was dominant in the 1990s, followed by *Canada Renette* and *Kalterer Böhmer*. The frequency of most varieties increased over the past 28 years. However, a decrease was observed for *Golden Delicious*, *Canada Renette*, and *Steinpeppinig*. Within both surveys, certain varieties could not be determined (Fig. 6).

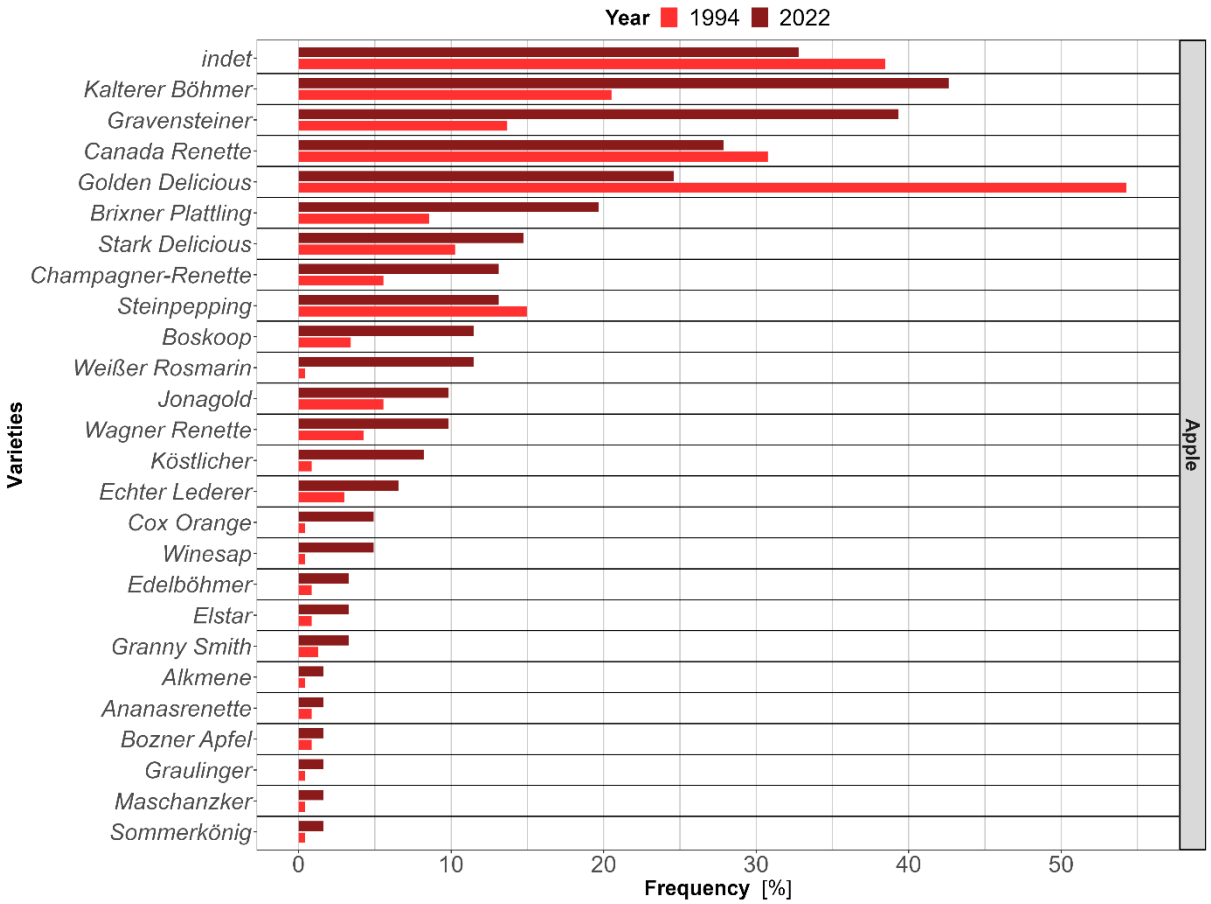

Figure 6: *Frequency of apple varieties found within surveyed orchard meadows in 1994 (Oberrauch 1997) and 2022. indet: indeterminate.*

Furthermore, 25 varieties were only found in 1994, which were dominated by *Goldpermäne*, *Jonathan*, *Morgenduft* and *Zwiefler*. On the other hand, 57 varieties were found only in 2022, including *Topaz*, *Wintergoldpermäne*, *Weißer Winter-Calville*, *Weißer Klarapfel*, *Tiroler Spitzlederer*, and *Gala Permäne* (Fig. S13).

3.3.2. Pears

Pears had the second most fruit varieties in the orchard meadows visited within both surveys. In 2022, 40 varieties of pear were found and only 17 in 1994 (Tab. S9); 11 of these varieties were observed in both surveys. In 2022, the varieties *Williams Christ*, *Kaiser Alexander*, and *Gute Luise von Avranches* occurred the most frequently. In 1994 on the other hand, pears were most often represented by *Palabirne* and *Pastorenbirne*. For most of these pear varieties, their occurrence increased since the 1990s, but for *Palabirne*, *Diels Butterbirne*, and *Honigbirne* it decreased. Just like apples, some pear varieties could not be determined within both surveys (Fig. 7).

Six pear varieties were only observed in the 1990s and 29 in 2022. In today's survey, these varieties were most often *Winterbirne* and *Klotze*. In 1994, the six varieties were *Olga*, *Winter Zitronenbirne*, *Holzbirne*, *Tillsbirne*, *Joggisbirne*, and *Jakobibirne* (Fig. S14).

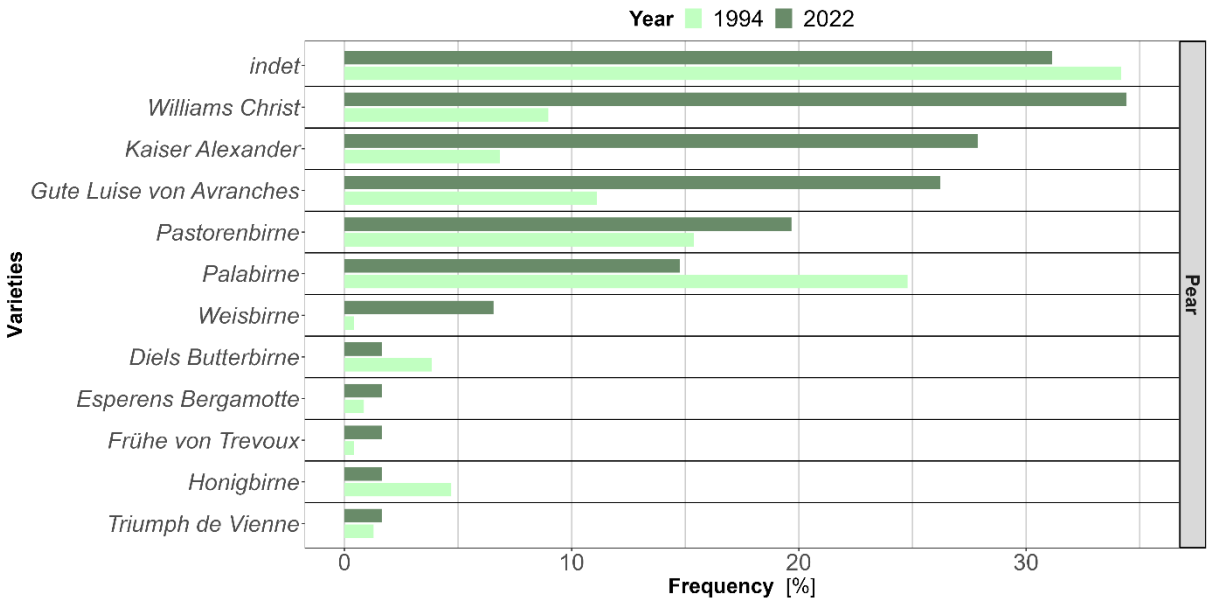

Figure 7: *Frequency of pear varieties found within surveyed orchard meadows in 1994 (Oberrauch 1997) and 2022. indet: indeterminate.*

3.4. Changes in agricultural management

The temporal comparison of different aspects provided information on changes in orchard meadow management. Currently, the understory is used slightly more frequently as a meadow, pasture, and/or for vegetable cultivation. However, a significant increase in the use as retreat for recreation was observed (Fig. 8a). In 2022 orchard meadows were used in 79% for recreation, either privately (83%) or for touristic purposes (17%; Fig. S15). In the 1990s, the understory in orchard meadows was used most often for one single management type. In 2022 however, managing the understory by two or more types became more frequent (Fig. S16), which was also reflected by the increase in the frequency of all four understory management classes (Fig. 8a).

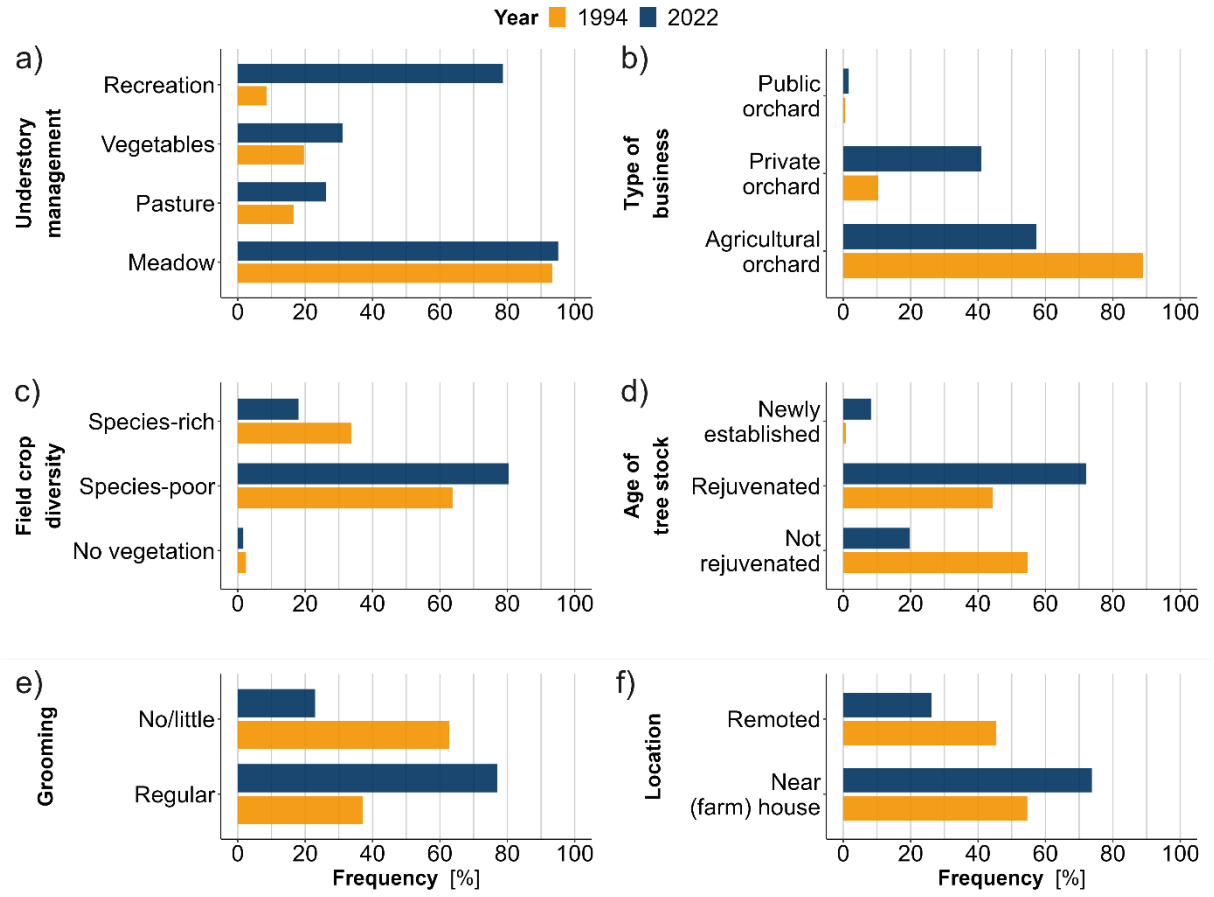

Figure 8: *Comparison of the frequency of different aspect of agricultural management in 1994 (Oberrauch 1997) and 2022: understory management* ***[a]****, type of business* ***[b]****, field crop diversity* ***[c]****, age of tree stock* ***[d]****, grooming* ***[e]****, and location* ***[f]****.*

Today’s orchard meadows were less frequently used for agricultural purposes, but were more often cultivated in private orchards (also associated with house gardens; Fig. 8b). In 2022, some agriculturally managed orchard meadows offered “holidays on a farm” (Farmers' Association of South Tyrol 2023), which is related to touristic recreation. In each survey year, one site was managed by a public institution (Fig. S17b). In the case of 2022, this orchard meadow served as a valuable cultural heritage of the local municipality.
The diversity of field crop species appeared to be poorer in 2022. Both in 1994 and 2022, very few orchard meadows also had no vegetation. The distribution however was similar in both survey years, whereat orchard meadows most frequently showed species-poor field crops (Fig. 8c).
In 1994, orchard meadows were more often observed to show an old age structure. Rejuvenated and also newly established orchard meadows occurred more frequently in 2022 (Fig. 8d)
The visited fields were more often observed to be better groomed in 2022. The frequency of well-groomed orchard meadows is nearly double as high as in the 1990s (Fig. 8e).
Furthermore, today’s orchards were more often located near the owners’ houses or farms. However, the distribution was similar in both survey years, whereat orchard meadows were situated less often at remote locations (Fig. 8f).

4. Discussion

Agroforestry systems combine both agriculture and forestry. They are still widely spread in Europe, especially in territories with Mediterranean, but also with temperate climate (in particular France; Plieninger *et al.* 2015a, Herder *et al.* 2017). Livestock agroforestry covers around 15% of European grasslands and, combined with cultivated fruit, olive, and nut trees, are most frequent in Spain (217,000ha), Greece (123,000ha), Portugal (122,700ha), and Italy (116,200ha). The distribution of Italy refers mainly to the southern and central Italian olive groves (Herder *et al.* 2017).

The most common agroforestry systems in South Tyrol are larch meadows and chestnut groves. Orchard meadows, on the other hand, are much less widespread (Nascimbene *et al.* 2014, Loos 2020). Today, larch meadows are still widely distributed (3,000ha; Fontana *et al.* 2014), despite the legally mandated separation of forests and pastures, and the boosting of the wood production (supported by forest development strategies), due to a high demand for wood after the Second World War (Chételat *et al.* 2013). Larch trees are a source of valuable products (timber, turpentine; Fontana *et al.* 2013, Loos 2020). They preferably grow in open locations (Nagler *et al.* 2015) and are therefore not suitable for cultivation in dense tree canopies (Loos 2020). However, larch grasslands have declined by a third of their original extent in South Tyrol since the 1950s (Fontana *et al.* 2014).

Chestnuts provide in addition to valuable wood products, also food and are widely spread throughout Europe (Fernández-López & Ricardo 2003, Conedera *et al.* 2004). The chestnut areas cover approximately 2.5 million ha in Europe, while the largest portion (79%) is grown in forests for timber production (chestnut forests). Fruit and timber production within agroforestry systems (chestnut groves) contributes to almost 18% of the total chestnut cover and is most common in Italy with an area of 235,620ha (Conedera *et al.* 2004). Chestnut groves have also decreased during the 20th century, especially due to land abandonment (Fernández-López & Ricardo 2003, Conedera *et al.* 2004). This development also occurred in South Tyrol (Radtke *et al.* 2013, Loos 2020). Before this decline, chestnuts provided a fundamental food source of livelihood in South Tyrol for a long time and today, they still have a high value in tradition and gastronomy (Loos 2020). Chestnut groves are closely related to fruit production in orchard meadows, whereat chestnut trees are also often interspersed (Weller 2014).

Orchard meadows are the youngest agroforestry system in South Tyrol (Loos 2020) and became only more frequent as a consequence of the Napoleonic War to improve the populations' food security after the 1820s (Oberhofer 2007a). As shown in this study, they still covered nearly 6,400ha in 1955 (7% of UAA in 1954; Tab. 1, Tab. S6) and decreased by -95% since then. A decline in orchard meadow areas occurred throughout Central

Europe (Tab. 4) and is estimated by -75% since the middle of the 1950s (Blume 2010). In the context of temperate Europe (Tab. 4), South Tyrol showed one of the highest declines. However, existing data on spatio-temporal development of orchard meadows are often based on estimations, or different collection guidelines and mostly refer to different time periods, which needs to be considered when comparing these data (Herzog 1998).

Table 4: *Collected data on orchard meadow decline in eight Central European countries and corresponding territories. For Britain, the decline of cider-orchards (silvopastoral system), which are almost identical to Central European orchard meadows (Schramayr 2001), is displayed.*

Country	Territory	Time period	Change [%]	Reference
Belgium		**1944 - 1976**	**-94**	(Weller 2014)
Luxemburg		**1902 - 1993**	**-78**	(Weller 2014)
Germany		**since 1950s**	**-75**	(Thieme *et al.* 2008)
	North-west	1979 - 2009	-74	(Forejt & Syrbe 2019)
	South	1965 - 2005	-48	(Plieninger *et al.* 2015b)
	East	1964 - 2008	-46	(Plieninger *et al.* 2015b)
	South-west	1968 - 2009	-22	(Forejt & Syrbe 2019)
	Hessen	1938 - 1983	-92	(Weller 2014)
	North Rhine-Westphalia	1951 - 1990	-92	(Weller 2014)
	Hamburg	1951 - 1965	-87	(Weller 2014)
	Rhineland-Palatinate	1951 - 1990	-84	(Weller 2014)
	Niedersachsen	1951 - 1965	-76	(Weller 2014)
	Bremen	1951 - 1965	-71	(Weller 2014)
	Baden-Württemberg	1938 - 1990	-70	(Hammel & Arnold 2012)
	Thuringia	1981 - 1988	-67	(Weller 2014)
	BRD-West	1951 - 1982	-65	(Weller 2014)
	Saarland	1965 - 1988	-61	(Weller 2014)
	Bavaria	1951 - 1965	-33	(Weller 2014)
Switzerland		**1954 - 1991**	**-70**	(Herzog 1998)
Austria		**1960 - 1984**	**-65**	(Weller 2014)
	Burgenland	19th century	-85	(Holler 2001)
	Mostviertel	1953 - 2002	-70	(Schönhart *et al.* 2011)
Britain		**1950 - 2007**	**-56**	(Burrough *et al.* 2010)
	England	1950 - 2007	-81	(Burrough *et al.* 2010)
	Wales	1950 - 2007	-81	(Burrough *et al.* 2010)
France		**1982 - 2003**	**-44**	(Plieninger *et al.* 2015b)
Slovakia				
	Central	since 1950s	-75	(Forejt & Syrbe 2019)
Czech Republic				
	Bohemia	since mid-1950s	-15	(Forejt & Syrbe 2019)

In Central Europe, orchard meadow loss occurred primarily due to intensification of agricultural practices, urbanization, and land abandonment (Herzog 1998, Eichhorn *et al.* 2006, Schönhart *et al.* 2011, Plieninger *et al.* 2015b, Zehnder & Weller 2016, Forejt & Syrbe 2019). As shown in this study, this was also the case in South Tyrol. The loss of orchard meadows in South Tyrol was mainly driven by agricultural intensification, while more than half of the area was transformed into modern orchards with small, densely planted trees/palmettes. Usually, orchard meadows in Central Europe are characterized by a tree density of 20 to 100 ind. ha^{-1} (Herzog 1998, Holler 2001, Plieninger *et al.* 2015b, Žarnovičan *et al.* 2020), but is in some cases also defined higher (up to 300 ind. ha^{-1}; Kornprobst 1994). In South Tyrol, historic orchard meadows usually showed tree densities of around 60 ind. ha^{-1} (Oberrauch 2001). Modern orchards, on the other hand, can have a density of up to 20,000 ind. ha^{-1} (highest profitability: ~ 5,000 ind. ha^{-1}; Gufler 1994, Werth 1994, Oberrauch 1997). Despite this immense increase of tree density in fruit production, the average density within orchard meadows has decreased in South Tyrol since the 1950s (Fig. 3, Fig. S8). In the 1990s, Oberrauch (1997) identified orchard meadows to be usually overaged. This was also the case for several survey sites that were visited within this study. Thus, the old age structure of the tree stock may be an explanation for the decline in average tree density, whereat single trees were occasionally removed without replacing it with a young one (rejuvenation). Additionally, agricultural intensification was also carried out in managed grasslands (especially meadows). In this case, many or even all trees were removed from these fields to allow, among other things, the use of machinery (Chételat *et al.* 2013). This may also have contributed to the decrease in tree density. Agricultural intensification led to the separation of the two main components of an orchard meadow: fruit and fodder production. This separation was further amplified by the use of pesticides in South Tyrol's fruit cultivation since the 1920s, which has had a negative impact on livestock (Oberhofer 2007e). However, other drivers have also to be considered, such as increased mechanization (Plieninger *et al.* 2012, Chételat *et al.* 2013, Rolo *et al.* 2020), increased use of fertilizers (Nerlich *et al.* 2013, Weller 2014), increased production cost (Schönhart *et al.* 2011, Fontana *et al.* 2014), as well as the development of full-time to part-time farming, and the reduction of household size (Fontana *et al.* 2014) leading to a decrease of free family labour resources (Herzog 1998, Schönhart *et al.* 2011).

Furthermore, urbanization had strongly contributed to the LULC change of historical orchard meadows in South Tyrol. Since the 1950s, the population increased by a factor of 3,2 (from 168,301 in 1951 to 532,616 inhabitants in 2020; ASTAT 2023a). Thus, built-up areas needed to be expanded and orchard meadow areas, which are often located in belts around settlements (Plieninger *et al.* 2015b), were removed during this process. Urbanization was also accompanied by the expansion of the infrastructure network (roads and railways;

Hilpold *et al.* 2020b). An important milestone was the construction of the highway A22 (1972), which, together with the establishment of new plantation and conservation technologies, facilitated an even stronger advancement of the specialization in intensive fruit production after the 1970s (Oberrauch 2001, Oberhofer 2007a).
A third driver of orchard meadow loss in South Tyrol was the abandonment of land, indicated by succession into forests. Land abandonment usually occurs in areas with less favourable socio-economic conditions (high elevation, high inclination, north-facing slopes; Plieninger *et al.* 2012) and thus may have especially contributed to the orchard meadow loss in such areas. Agricultural intensification and urbanization, on the other hand, had probably occurred in areas with more suitable topographic properties (low elevation, low inclination, south-facing slopes, Hilpold *et al.* 2020a), given that these areas had experienced the highest decline in orchard meadows in South Tyrol. Furthermore, most of the intensive orchards in South Tyrol today are located on shallow, broad valley floors within the districts of Überetsch-Südtiroler Unterland, Bozen, Burggrafenamt, and Vinschgau (LAFIS 2021). These areas are used primarily to produce apples and wine (ASTAT 2018). However, vineyards can also be found on lower mountain slopes. In South Tyrol, apples and wine can be intensively cultivated up to an elevation of 1,000m a.s.l. (Hilpold *et al.* 2020b). Thus, orchard meadows were most likely to be preserved at higher elevations.

4.1. Provision of ecosystem services (ES)

Agroforestry systems, including orchard meadows, provide numerous ES (Tab. 5). The transition of LULC usually leads to changes in the provision of ES (Foley *et al.* 2005). As a consequence of agricultural intensification, urbanization, and land abandonment, landscape heterogeneity and biodiversity have been reduced, which resulted in a loss of rare habitats and their associated flora and fauna (Tasser *et al.* 2008, Weller 2014, Hilpold *et al.* 2020a, Žarnovičan *et al.* 2020). Orchard meadows are inhabited by numerous species and are biodiversity hotspots (Weller 2014, Forejt & Syrbe 2019). For instance, extensively managed, traditional orchards within South Tyrol show significantly higher levels of taxonomical richness and diversity of soil macro-invertebrate communities, in contrast to intensively managed orchards (Guariento *et al.* 2020, Moosgöller ongoing). Furthermore, the communities within intensive orchards are strongly dependent on intensity and type of management. Other groups of organisms are currently monitored throughout a special project of the Biodiversity Monitoring South Tyrol (BMS; Eurac Research 2021), which includes a detailed survey of five orchard meadows and five intensive apple plantations.

Table 5: *List of several ecosystem services (Haines-Young & Potschin 2018) provided in agroforestry systems.*

Provisioning	Regulation & maintenance	Cultural
Fibre [12, 14;]	Air quality improvement [7, 8, 14;]	Aesthetic values [2, 6, 7, 8, 12, 16;]
Fodder [6, 7, 8, 12, 14;]	Climate regulation [6, 8, 12, 13, 14;]	Conservation of many fruit and crop varieties [1, 8;]
Food [3, 7, 8, 12, 14, 15, 16;]	Erosion control [4, 12, 13;]	Environmental education [8, 13, 14;]
Genetic resources [10, 12, 14;]	Flood mitigation [8, 13;]	Knowledge of traditional agricultural practices [2, 10, 12;]
Timber [6, 7, 14;]	Groundwater protection [7, 8;]	Recreation & ecotourism [2, 4, 6, 8, 12, 13, 14, 16;]
	Nutrient cycling [3, 10, 12, 14;]	Sense of place [2, 4, 12, 14;]
	Pest and disease control [5, 15;]	Social relations [8, 12, 14;]
	Pollination [1, 2, 14;]	Spiritual and religious values [2, 8, 12;]
	Provision of habitat & biodiversity [3, 7, 8, 12, 13, 15, 17;]	
	Soil conservation [3, 7, 8, 17;]	
	Storm protection [12;]	
	Water purification [3, 6, 7, 11, 12, 13, 14;]	

[1]Kornprobst 1994, [2]Herzog 1998, [3]Nair *et al.* 2008, [4]Schönhart *et al.* 2011, [5]Plieninger 2012, [6]Fontana *et al.* 2013, [7]Nerlich *et al.* 2013, [8]Plieninger *et al.* 2013, [9]Fontana *et al.* 2014, [10]Plieninger *et al.* 2015a, [11]Plieninger *et al.* 2015b, [12]Fagerholm *et al.* 2016, [13]Forejt & Syrbe 2019, [14]Zerbe 2019, [14]Guariento *et al.* 2020, [15]López-Sánchez *et al.* 2020, [16]Rolo *et al.* 2020

Regarding the species richness, first results indicate a significant difference between these two habitats, whereat orchard meadows showed higher diversity of vascular plants, grasshoppers, butterflies, and birds. In addition, some rare and/or endangered species were found in orchard meadows, for example, *Allium vineale* and *Orobanche lutea* (vascular plants), *Pachytrachis striolatus* and *Meconema thalassinum* (grasshoppers), *Melitaea didyma* and *Lycaena tityrus* (butterflies), and *Lanius collurio* and *Emberiza cia* (birds). Furthermore, the orchard meadows were inhabited by almost 70 species of bees, including a large portion of solitary and specialistic bees. On the other hand, only 25 bee species were found in intensive apple plantations (Guariento 2022). Traditional orchards are therefore also important for pollination and are thus often combined with beekeeping (Kornprobst 1994, Herzog 1998, Zerbe 2019). However, a high abundance of the honey bee (*Apis melifera*) often leads to the displacement of wild bee species (Kornprobst 1994). Another aspect of ESS within orchard meadows is the genetic diversity of fruit species, which has also been highly threatened by the intensification of fruit production (Herzog 1998, Weller 2014). The most frequent fruit species within orchard meadows are usually apples and pears. At the turn of the 20th century, around 200 apple and pear varieties were commercially produced in South Tyrol (Oberrauch 2001). Furthermore, the ratio of apples to pears was approximately 5:1 in 1955 (apples: 173,290t, pears: 31,860t; ASTAT 2018). Today, three quarters of the fruit cultivation area consists of intensive apple production (18,560ha in 2016; ASTAT 2018), on which around one million tons are harvested annually

(2014: 1.2Mt; Chamber of Commerce of Bolzano 2023). Thus, this poaceous fruit species is well studied in this region (Guerra *et al.* 2019). However, today's production is based mainly on eleven varieties (77% in 2022; especially *Golden Delicious*: 25%; Chamber of Commerce of Bolzano 2023). Pears, on the other hand, only play a minor role in today's fruit production (432t in 2022; Chamber of Commerce of Bolzano 2023) and is mainly focused on two varieties (*Williams Christ*: 70%, *Kaiser Alexander*: 0.2%). Therefore, apple production has been strongly increasing and pear production has been strongly decreasing over the last decades, leading to an apple to pear ratio of nearly 2,000:1 in recent years. Other poaceous fruits, as well as stone fruits and nuts, play only a minor role in the intensive fruit cultivation of South Tyrol (ASTAT 2018).

Nevertheless, this study has observed an increase in diversity of fruit species within orchard meadows since the 1990s, whereat khakis, pomegranates, and olives may have been newly cultivated (verbal agreement: Oberrauch 2022). Furthermore, more fruit varieties have been determined in the 2022 survey. However, numerous varieties could not be determined in the survey of 1994 (Oberrauch 1997), which means that no clear statements can be made about the development of the varieties. For example, only 131 apple varieties were identified in South Tyrol through the project "POMOSANO" (Versuchszentrum Laimburg 2016). In contrast, 2,504 apple, 1,623 pear, and 1,696 plum/damson varieties were identified in Swiss, 1,067 apple, 168 pear, and 1,000 plum/damson varieties in Germany, and 2,000 apple, 1,500 pear, and 1,000 plum/damson varieties were estimated in Austria (Gantar *et al.* 2011). Thus, a general increase in fruit varieties in South Tyrol's orchard meadows cannot be assumed.

4.2. Practical implications for the protection of orchard meadows

In South Tyrol, subsidies are currently available only for agriculturally managed orchard meadows, together with chestnut groves, through the "programme for landscape conservation" (premium: 550€ ha^{-1}; Abteilung Natur, Landschaft und Raumentwicklung 2021) and are linked to additional administrative efforts: minimum tree canopy cover of 20%, minimum area of 0.36ha (if not combined with another category, covered by this subsidy program; possible variations depending on the degree of topographic difficulties), and the commitment to keep the orchards for at least five years. Furthermore, the use of mineral or liquid fertilizers, and pesticides is not allowed and fallen branches, as well as competing shrubs must be removed. Nonetheless, the subsidies are only available after the trees are old enough to grow fruits. Currently, around 500 sites, of which only 20 are orchard meadows (55% smaller than 0.1ha), are enlisted to these subsidy program (LAFIS 2021). The use of agricultural land is closely related to profitability and to the compensation

payments received (Nishizawa *et al.* 2022). Compared to the results of this study, 99% of the mapped orchard meadows are therefore not supported by any subsidies, indicating that this programme is currently not well-adjusted to the requirements of cultivating an orchard meadow profitably or at least cost-covering. In contrast to this, there are subsidy programmes for agroforestry in Switzerland, where each high-stemmed tree is supported with 15 to 50 CHF annually (example with 80 ind. ha^{-1}: 1,200 to 4,000 CHF ha^{-1} a^{-1}; Kaeser *et al.* 2011). In addition, several organization are promoting newly established agroforestry systems with financial support (Schuler 2022). For example, the association “Hochstamm Suisse”, in collaboration with “Stiftung myclimate”, currently supports the replanting and grooming of high-stem trees with 105 CHF per tree (Hochstamm Suisse & myclimate 2022). In combination with good market prices, this financial support facilitates a strong economic competitiveness of agroforestry systems (Kaeser *et al.* 2011), including orchard meadows. This study shows an increased frequency of orchard meadow management as private gardens, whereat self-sufficiency prevails and high diversity in fruit composition is often desired. However, in an agricultural perspective, most of the visited orchard meadows were only supported by the personal interest of the owners. A small fraction sold the harvested fruits to fruit associations, gastronomic facilities, or at local farmers markets. Other farms offered “holidays on a farm” (Farmers' Association of South Tyrol 2023), whereat orchard meadows were used as a retreat for the guests, offering a business opportunity in tourism. Despite all these opportunities, orchard meadows are not economically competitive to modern agricultural systems in South Tyrol. Thus, orchard meadows are under constant pressure and are highly threatened of extinction, due to the ongoing intensification of agriculture and unsuitable economic conditions (Oberrauch 2001, Eichhorn *et al.* 2006, Oberhofer 2007a, Weller 2014). In regard of sustainable land use, the amount of provided ES is however more relevant than private economic efficiency (Herzog 1998). Local initiatives are working to sensibilize the public, local stakeholders, as well as administrative authorities to the importance of the functionalities and ES provided within orchard meadows, for example, “Sortengarten Südtirol” (Sortengarten Südtirol 2023) and “Initiative Baumgart” (Initiative Baumgart 2021), in order to conserve and promote orchard meadows in the cultural landscape of South Tyrol.

4.3. Methodical discussion

The mapping process within this study was not without inaccuracies. This includes, for example, discrepancies in the digital orthophotos used. They show different resolutions and qualities (pixel size, colour spectrum; Fig. S2) and do not perfectly overlap at all areas (problem of georectification), causing discrepancies of up to 25m. Moreover, both

orthophotos are influenced by the topography, the camera angle, and the illumination conditions. Referring to the historical orthophoto, the identification of orchard meadows was thus especially difficult in darker areas and fruit trees were hard to distinguish from other tree cover, due to the grey-scale tones. In relation to the current orthophoto, some potential orchard meadow areas, which were shaded by nearby forests or buildings, may have been missed. The identification of fruit trees was, however, easier for this time step and was sometimes also assisted by the tree shadows, if the light exposure has been suitable. In some cases, a confusion of fruit trees with other deciduous tree cover might also have occurred, possibly causing a similar error rate as the historical distribution (personal estimation: 5% error rate). The accuracy of the mapping process may be improved by an on-site verification of the identified orchard meadows. This was, however, not possible within this study, due to limited resources. Moreover, a verification is only possible for the current distribution of orchard meadows, which would inevitably lower the comparability of both datasets. Nevertheless, the exact distribution of orchard meadows should be monitored periodically, to ensure the endurance of this rare LULC type.

The comparison of the field study results was also not free of inaccuracies. The survey in the 1990s focused on investigating the entirety of orchard meadows within only three municipalities in South Tyrol (Feldthurns and Schluderns in Vinschgau, and Kiens in Pustertal). In this period, these three municipalities were not yet strongly affected by the intensification of fruit production (Oberrauch 1997). On the other hand, the investigation within this study was based on self-registration by the owners of the orchard meadows. Thus, the visited sites were unequally distributed throughout South Tyrol, whereat most of the visited orchard meadows were located in Eisacktal and Vinschgau and also newly established orchard meadows were mainly situated in Vinschgau (Tab. S3). The distribution of the surveyed orchards, moreover, does not reflect the overall distribution within South Tyrol (Tab. 3). Therefore, both surveys may not represent the entire orchards meadows in South Tyrol. However, long-term studies and agricultural censuses focus mainly on modern agricultural systems (ASTAT 2023b, ISTAT 2023) and similar data for orchard meadows are not available. The diverse fruit composition of orchard meadows forms a genetic reservoir of local and regional varieties, which was greatly threatened by their decline. Thus, orchard meadows should be periodically monitored, and the conservation of this diversity should be strongly supported. Nonetheless, the interest in a divers fruit composition has apparently risen. In the 2022 survey, for instance, most interviewees valued a high degree of fruit diversity, and some of them even provided an exact list of the planted fruit varieties, which was, however, not observed in the 1990s (personal communication: Oberrauch 2022).

5. CONCLUSION

In conclusion, orchard meadows are threatened to completely disappear from the cultural landscape of South Tyrol, showing one of the strongest declines in Central Europe since the middle of the twentieth century. They still represent a genetic reservoir for a great number of fruit varieties, especially apples and pears, which has potentially also decreased due to agricultural intensification and due to exceptionally old age structures within orchard meadows. Furthermore, orchard meadows are key elements for biodiversity and ES provision, thus representing an opportunity to structure the cultural landscape of South Tyrol more ecologically sustainable. However, regional subsidy programs currently target only the conservation of valuable landscape elements, rather than supporting the economic competitiveness of traditional agroforestry systems. This may have led to the increase of orchard meadow cultivation as private house gardens, where self-subsistence and recreational purposes prevail.

The extensive management in an agricultural context plays, however, an important role for the conservation of orchard meadows and for the provision of several ES, especially the provision of habitat and biodiversity. Therefore, orchard meadows should be monitored in more detail and included in upcoming agricultural censuses, in order to:

- assist conservation strategies,
- determine the spectrum of fruit varieties to conserve the genetic diversity, especially for local or regional varieties,
- and identify key challenges for promoting their spreading.

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Eidesstattliche Erklärung

Ich erkläre hiermit an Eides statt durch meine eigenhändige Unterschrift, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe. Alle Stellen, die wörtlich oder inhaltlich den angegebenen Quellen entnommen wurden, sind als solche kenntlich gemacht.

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Datum	Unterschrift

SUPPLEMENTARY

Tables

Table S1: *Classification of the topographic parameters elevation [**a**], slope [**b**], and exposition [**c**, **d**].*

		Class	Acronym	Value range
a)	**Elevation**	based on: Amt für Forstplanung 2010		**[m a.s.l.]**
		Colline		< 800
		Submontane		800 - 1.200
		Montane		1.200 - 1.800
b)	**Slope**			**[°]**
		Flat		< 1
		Gentle		1 - 11
		Moderate		11 - 21
		Steep		21 - 31
		Very steep		> 31
c)	**Exposition**			**[°]**
		North		270 - 90
		South		90 - 270
d)	**Exposition**	based on: Burrough *et al.* 2015		**[°]**
		North	N	337.5 - 22.5
		Northeast	NE	22.5 - 67.5
		East	E	67.5 - 112.5
		Southeast	SE	112.5 - 157.5
		South	S	157.5 - 202.5
		Southwest	SW	202.5 - 247.5
		West	W	247.5 - 292.5
		Northwest	NW	292.5 - 337.5

Table S2: *Land-use/land-cover (LULC) types in South Tyrol (Anderle et al. 2022) divided into main groups. (*): not relevant for LULC change analysis.*

LULC groups	LULC types	
Built-up area	11000 - Artificial surfaces and constructions	
	11100 - Dense settlement area	
	11200 - Low density settlement area	
	11300 – Built-up area	
	11400 - Open settlement area	
	12100 - Industrial and commercial zones	
	14100 - Green urban areas	
	31450 - Tree cover in urban context	
Infrastructure	12210 - Roads motorways and trunks	
	12220 - Road networks	
	12221 - Roads tertiary and others	
	12230 - Railways train tracks	
	12240 - Unpaved roads and tracks	
Arable land	21000 - Cultivated areas - Arable land - Annual crops	
	21211 - Common wheat	
	21213 - Barley	
	21214 - Rye	
	21215 - Oats	(*)
	21216 - Maize	
	21218 - Triticale	(*)
	21219 - Other cereals	(*)
	21221 - Potatoes	
	21222 - Sugar beet	
	21223 - Other root crops	(*)
	21230 - Other non-permanent industrial crops	(*)
	21231 - Sunflower	
	21232 - Rape and turnip rape	
	21233 - Soya	
	21240 - Dry pulses	
	21250 - Fodder crops (cereals and leguminous)	
	21290 - Bare arable land	
Orchards	22000 - Permanent crops	
	22200 - Orchards	
	31400 - Tree cover in agricultural context	
Vineyards	22100 - Vineyard	
Orchard meadows	22300 - Orchard Meadow	
Grassland	23100 - Managed grassland - Pastures	
	23200 - Seminatural grassland - Meadows	
	32100 - Alpine and sub-alpine natural grassland	(*)
Forests	31100 - Broadleaf tree cover	
	31102 - Broadleaf tree cover 30-60%	
	31103 - Broadleaf tree cover 60-100%	
	31200 - Coniferous tree cover	
	31202 - Coniferous tree cover 30-60%	
	31203 - Coniferous tree cover 60-100%	
	31300 - Mixed tree cover	
Woody features and shrubland	31500 - Green linear elements - linear woody features	
	31600 - Patchy woody features	
	31610 - Additional woody features	
	32000 - Scrub and shrubland	
	32300 - Sclerophyllous vegetation	(*)
Wetland	32200 - Moors and heathland - other scrubland	
	41000 - Wetland (permanent wet areas) - inland marshes	
Bare rocks and rock debris	33100 - Beaches, dunes, sands	(*)
	33200 - Bare rocks and rock debris	
	33300 - Sparsely vegetated land	
Waterbodies	33500 - Permanent snow covered surfaces	(*)
	51000 - Water bodies	
	51100 – River network	
	51200 - Riverbed > 10m width	

Table S3: *Distribution of the 61 surveyed orchard meadows throughout the districts of South Tyrol.*

	N	
	Orchard meadows	**Newly established**
Bozen	1	-
Burggrafenamt	5	-
Eisacktal	17	-
Pustertal	6	-
Salten–Schlern	7	1
Überetsch-Südtiroler Unterland	6	-
Vinschgau	10	4
Wipptal	4	-
South Tyrol	**56**	**5**

Table S4: *Properties of the survey sites within this study compared to those in 1994 (Oberrauch 1997). For the survey sites in 1994, no data (n.d.) is available for the surface area.*

		1994	**2022**
N_{sites}			
		234	61
N_{area} **[%]**			
	< 0.1 ha	n.d.	43
	≥ 0.1ha	n.d.	57
$N_{exposition}$ **[%]**			
	none	32	-
	South	55	66
	North	13	34
$Elevation$ **[m a.s.l.]**			
	mean	923 ± 92	842 ± 222
	min	585	244
	max	1195	1214
$Slope$ **[°]**			
	mean	9.2 ± 9	10.2 ± 8.5
	min	0	1
	max	37	49

Table S5: *R packages used during the evaluation of spatial and topographic variables within R (R Core Team 2022).*

Statistical packages		**Graphical packages**	
Name	**Reference**	**Name**	**Reference**
tidyverse v1.3.2	(Wickham *et al.* 2019)	tidyverse v1.3.2	(Wickham *et al.* 2019)
psych v2.2.9	(Revelle 2022)	ggsignif v0.6.4	(Constantin & Patil 2021)
car v3.1-1	(Fox & Weisberg 2019)	ggpubr v0.6.0	(Kassambara 2023)
carData v3.0-5	(Fox *et al.* 2022)	ggpol v0.0.7	(Tiedemann 2020)
		ggradar v0.2	(Bion 2022)
		ggalluvial v0.12.4	(Cory Brunson & Read 2023)

Table S6: *Orchard meadow area in South Tyrol and its districts in the 1950s and today, their change over time in percent, and the percentage of orchard meadow area (A_{OM}), by the used agricultural area (A_{UAA}, Tab. 1).*

	Orchard meadow area in:			A_{OM} A_{UAA}^{-1} [%] in:	
	1954-56 [ha]	2020 [ha]	Change [%]	Historical	Recent
Bozen	320.2	1.6	-99.5	19.64	0.09
Burggrafenamt	1,964.1	65.5	-96.7	12.95	0.42
Eisacktal	497.4	41.8	-91.6	4.57	0.44
Pustertal	250.2	52.1	-79.2	1.09	0.24
Salten-Schlern	211.3	35.6	-83.1	1.50	0.23
Überetsch - Südtiroler Unterland	1,637.5	10.2	-99.4	12.27	0.08
Vinschgau	1,455.8	84.7	-94.2	12.00	0.75
Wipptal	28.5	5.0	-82.7	0.44	0.09
South Tyrol	6,364.9	296.4	-95.3	6.58	0.32

Table S7: *Results of the total area of orchard meadows in South Tyrol, categorized by elevation [**a**], slope [**b**], and exposition [**c**, **d**].*

		Area [ha]		Area [%]		Change [ha]	Change [%]
		1954-56	2020	1954-56	2020		
a)	Elevation						
	Colline	5,219	64	82	21	-5,155	-98.8
	Submontane	875	155	14	52	-720	-82.3
	Montane	272	78	4	26	-193	-71.2
b)	Slope						
	Flat	459	7	7	2	-453	-98.6
	Gentle	4,387	74	69	25	-4,313	-98.3
	Moderate	1,043	92	16	31	-951	-91.2
	Steep	407	100	6	34	-307	-75.5
	Very steep	68	24	1	8	-44	-64.8
c)	Exposition						
	South	5,035	216	79	73	-4,819	-95.7
	North	1,330	80	21	27	-1,250	-94.0
d)	Exposition						
	N	35	11	0.5	3.7	-23.8	-68.4
	NE	253	26	4.0	8.6	-227.7	-89.9
	E	815	49	12.8	16.6	-765.5	-94.0
	SE	1,897	52	29.8	17.5	-1844.8	-97.3
	S	1,776	63	27.9	21.4	-1712.3	-96.4
	SW	643	57	10.1	19.3	-585.6	-91.1
	W	511	25	8.0	8.5	-485.8	-95.1
	NW	440	13	6.9	4.4	-427.4	-97.0

Table S8: *Land-use/land-cover (LULC) change of orchard meadows in South Tyrol and in its districts since the 1950s. A_{OM}: orchard meadow area; A_{LUC}: area of LULC change; A_{UAA}: used agricultural area in 2010.*

	A_{OM} [ha]	LULC groups	A_{LUC} [ha]	A_{LUC} [%]	A_{UAA} [%]
South Tyrol	6,365	Orchards	3,564	56.0	3.80
		Built-up areas	908	14.3	
		Infrastructure	537	8.4	
		Grassland	520	8.2	0.55
		Forests	380	6.0	
		Vineyards	192	3.0	0.21
		Arable land	107	1.7	0.11
		Woody features and shrubland	100	1.6	
		Orchard meadows	33	0.5	0.04
		Waterbodies	17	0.3	
		Bare rocks and rock debris	5	< 0.1	
		Wetland	1	< 0.1	
Bozen	320	Orchards	183	57.2	10.5
		Built-up areas	89	27.8	
		Infrastructure	31	9.6	
		Vineyards	6	1.9	0.34
		Grassland	5	1.5	0.27
		Forests	3	1.0	
		Arable land	1	0.4	0.08
		Waterbodies	< 1	0.2	
		Woody features and shrubland	< 1	0.2	
		Orchard meadows	< 1	< 0.1	0.01
		Wetland	< 1	< 0.1	
Burggrafenamt	1,964	Orchards	1,193	60.7	7.71
		Built-up areas	287	14.6	
		Grassland	175	8.9	1.13
		Infrastructure	139	7.1	
		Forests	79	4.0	
		Woody features and shrubland	28	1.4	
		Vineyards	25	1.3	0.16
		Arable land	22	1.1	0.15
		Orchard meadows	9	0.5	0.06
		Waterbodies	4	0.2	
		Bare rocks and rock debris	3	0.1	
		Wetland	< 1	< 0.1	

continue ***Table S8:***

	A_{OM} [ha]	LULC groups	A_{LUC} [ha]	A_{LUC} [%]	A_{UAA} [%]
Eisacktal	497	Grassland	116	23.3	1.22
		Built-up areas	105	21.1	
		Orchards	100	20.1	1.05
		Forests	72	14.4	
		Infrastructure	46	9.3	
		Woody features and shrubland	24	4.9	
		Arable land	14	2.9	0.15
		Vineyards	13	2.6	0.14
		Orchard meadows	4	0.8	0.04
		Waterbodies	2	0.5	
		Bare rocks and rock debris	< 1	0.1	
		Wetland	< 1	< 0.1	
Pustertal	250	Forests	76	30.3	
		Grassland	68	27.3	0.31
		Built-up areas	30	12.2	
		Arable land	30	12.0	0.14
		Woody features and shrubland	18	7.1	
		Infrastructure	16	6.3	
		Orchards	7	2.8	0.03
		Orchard meadows	5	2.0	0.02
		Waterbodies	< 1	< 0.1	
		Wetland	< 1	< 0.1	
		Bare rocks and rock debris	< 1	< 0.1	
Salten-Schlern	211	Grassland	83	39.4	0.54
		Forests	60	28.2	
		Built-up areas	25	11.7	
		Intensive orchards	16	7.5	0.10
		Infrastructure	13	6.1	
		Woody features and shrubland	6	2.8	
		Vineyards	3	1.6	0.02
		Arable land	3	1.5	0.02
		Orchard meadows	2	1.1	0.02
		Waterbodies	< 1	< 0.1	
		Bare rocks and rock debris	< 1	< 0.1	

continue ***Table S8:***

	A_{OM} [ha]	LULC groups	A_{LUC} [ha]	A_{LUC} [%]	A_{UAA} [%]
Überetsch-Südtiroler Unterland	1,638	Intensive orchards	1,111	67.9	8.70
		Built-up areas	161	9.8	
		Vineyards	138	8.4	1.08
		Infrastructure	127	7.8	
		Forests	43	2.6	
		Grassland	31	1.9	0.24
		Arable land	14	0.9	0.11
		Woody features and shrubland	6	0.4	
		Waterbodies	5	0.3	
		Wetland	< 1	< 0.1	
		Bare rocks and rock debris	< 1	< 0.1	
		Orchard meadows	< 1	< 0.1	< 0.01
Vinschgau	1,456	Orchards	954	65.5	8.44
		Built-up areas	208	14.3	
		Infrastructure	163	11.2	
		Forests	40	2.8	
		Grassland	31	2.1	0.27
		Arable land	19	1.3	0.17
		Woody features and shrubland	16	1.1	
		Orchard meadows	12	0.8	0.10
		Vineyards	7	0.5	0.06
		Waterbodies	5	0.4	
		Bare rocks and rock debris	< 1	< 0.1	
		Wetland	< 1	< 0.1	
Wipptal	29	Grassland	11	40.1	0.20
		Forests	7	23.8	
		Built-up areas	3	10.9	
		Arable land	2	8.4	0.04
		Infrastructure	2	5.7	
		Woody features and shrubland	2	5.3	
		Orchards	1	5.2	0.03
		Orchard meadows	< 1	0.6	< 0.01
		Waterbodies	< 1	< 0.1	

Table S9: *Comparison of fruit species in their number of varieties ($N_{varieties}$) and occurrences ($N_{occurrence}$) in the surveyed orchard meadows in 1994 (Oberrauch 1997) and 2022. The list includes a differentiation between determined (det), undetermined ($indet$) varieties, and their sum.*

Year	Sites	Fruit type	Fruit species	$N_{varieties}$			$N_{occurrences}$		
				det	***indet***	***sum***	***det***	***indet***	***sum***
		Stone fruit	Almond	-	-	-	-	-	-
		Poaceous fruit	Apple	50	1	51	517	90	607
		Stone fruit	Apricot	-	1	1	-	76	76
		Stone fruit	Cherry	-	1	1	-	102	102
		Nuts	Chestnut	1	-	1	2	-	2
		Stone fruit	Damson	-	1	1	-	96	96
		Stone fruit (others)	Fig	-	1	1	-	4	4
		Stone fruit	Greengage	-	1	1	-	17	17
		Nuts	Hazelnut	-	-	-	-	-	-
1994	234	Soft fruit	Khaki	-	-	-	-	-	-
		Poaceous fruit	Medlar	-	-	-	-	-	-
		Soft fruit	Mulberry	-	-	-	-	-	-
		Stone fruit (others)	Olive	-	-	-	-	-	-
		Stone fruit	Peach	-	1	1	-	30	30
		Poaceous fruit	Pear	17	1	18	199	80	279
		Stone fruit	Plum	-	1	1	-	30	30
		Soft fruit	Pomegranate	-	-	-	-	-	-
		Poaceous fruit	Quince	1	1	2	3	8	11
		Nuts	Walnut	-	1	1	-	87	87
		Stone fruit	Almond	1	1	2	1	5	6
		Poaceous fruit	Apple	83	1	84	271	20	291
		Stone fruit	Apricot	15	1	16	23	23	46
		Stone fruit	Cherry	8	1	9	15	30	45
		Nuts	Chestnut	1	-	1	16	-	16
		Stone fruit	Damson	15	1	16	19	36	55
		Stone fruit (others)	Fig	-	1	1	-	7	7
		Stone fruit	Greengage	2	1	3	4	8	12
		Nuts	Hazelnut	-	1	1	-	2	2
2022	61	Soft fruit	Khaki	2	-	2	13	-	13
		Poaceous fruit	Medlar	2	1	3	2	2	4
		Soft fruit	Mulberry	-	1	1	-	1	1
		Stone fruit (others)	Olive	-	1	1	-	1	1
		Stone fruit	Peach	9	1	10	12	12	24
		Poaceous fruit	Pear	40	1	41	120	19	139
		Stone fruit	Plum	7	1	8	7	8	15
		Soft fruit	Pomegranate	-	1	1	-	1	1
		Poaceous fruit	Quince	2	1	3	4	6	10
		Nuts	Walnut	-	1	1	-	27	27

Table S10: *Comparison of fruit species in their average number of varieties ($\bar{N}_{varieties}$) in the surveyed orchard meadows in 1994 (Oberrauch 1997) and 2022. The list includes a differentiation between determined (det), undetermined ($indet$) varieties, and their sum.*

Year	Sites	Fruit type	Fruit species	$\bar{N}_{varieties}$		
				det	$indet$	sum
1994	234	Stone fruit	Almond	-	-	-
		Poaceous fruit	Apple	2.21 ± 21.84	0.39	2.59 ± 24.33
		Stone fruit	Apricot	-	0.33	0.33 -
		Stone fruit	Cherry	-	0.44	0.44 -
		Nuts	Chestnut	0.01 -	-	0.01 -
		Stone fruit	Damson	-	0.41	0.41 -
		Stone fruit (others)	Fig	-	0.02	0.02 -
		Stone fruit	Greengage	-	0.07	0.07 -
		Nuts	Hazelnut	-	-	-
		Soft fruit	Khaki	-	-	-
		Poaceous fruit	Medlar	-	-	-
		Soft fruit	Mulberry	-	-	-
		Stone fruit (others)	Olive	-	-	-
		Stone fruit	Peach	-	0.13	0.13 -
		Poaceous fruit	Pear	0.85 ± 15.76	0.34	1.19 ± 22.20
		Stone fruit	Plum	-	0.13	0.13 -
		Soft fruit	Pomegranate	-	-	-
		Poaceous fruit	Quince	0.01 -	0.03	0.05 ± 3.54
		Nuts	Walnut	-	0.37	0.37 -
2022	61	Stone fruit	Almond	0.02 -	0.08	0.10 ± 2.83
		Poaceous fruit	Apple	4.44 ± 4.63	0.33	4.77 ± 4.95
		Stone fruit	Apricot	0.38 ± 1.81	0.38	0.75 ± 5.64
		Stone fruit	Cherry	0.25 ± 1.13	0.49	0.74 ± 9.43
		Nuts	Chestnut	0.26 -	-	0.26 -
		Stone fruit	Damson	0.31 ± 0.59	0.59	0.90 ± 8.70
		Stone fruit (others)	Fig	-	0.12	0.12 -
		Stone fruit	Greengage	0.07 ± 1.41	0.13	0.20 ± 3.61
		Nuts	Hazelnut	-	0.03	0.03 -
		Soft fruit	Khaki	0.21 ± 3.54	-	0.21 ± 3.54
		Poaceous fruit	Medlar	0.03 -	0.03	0.07 ± 0.58
		Soft fruit	Mulberry	-	0.02	0.02 -
		Stone fruit (others)	Olive	-	0.02	0.02 -
		Stone fruit	Peach	0.20 ± 1.00	0.20	0.39 ± 3.50
		Poaceous fruit	Pear	1.97 ± 4.91	0.31	2.28 ± 5.45
		Stone fruit	Plum	0.12 -	0.13	0.25 ± 2.48
		Soft fruit	Pomegranate	-	0.02	0.02 -
		Poaceous fruit	Quince	0.07 ± 1.41	0.10	0.16 ± 2.52
		Nuts	Walnut	-	0.44	0.44 -

Table S11: *Comparison of fruit species in their average number of occurrence ($N_{frequency}$) and average number in occurrence by percent in the surveyed orchard meadows in 1994 (Oberrauch 1997) and 2022. The list includes a differentiation between determined (det), undetermined ($indet$) varieties, and their sum.*

Year	Sites	Fruit type	Fruit species	$N_{frequency}$			$N_{frequency}$ [%]		
				det	***indet***	***sum***	***det***	***indet***	***sum***
		Stone fruit	almond	-	-	-	-	-	-
		Poaceous fruit	apple	10	90	12	4	38	5
		Stone fruit	apricot	-	76	76	-	32	32
		Stone fruit	cherry	-	102	102	-	44	44
		Nuts	chestnut	2	-	2	1	-	1
		Stone fruit	damson	-	96	96	-	41	41
		Stone fruit (others)	fig	-	4	4	-	2	2
		Stone fruit	greengage	-	17	17	-	7	7
		Nuts	hazelnut	-	-	-	-	-	-
1994	234	Soft fruit	khaki	-	-	-	-	-	-
		Poaceous fruit	medlar	-	-	-	-	-	-
		Soft fruit	mulberry	-	-	-	-	-	-
		Stone fruit (others)	olive	-	-	-	-	-	-
		Stone fruit	peach	-	30	30	-	13	13
		Poaceous fruit	pear	12	80	16	5	34	7
		Stone fruit	plum	-	30	30	-	13	13
		Soft fruit	pomegranate	-	-	-	-	-	-
		Poaceous fruit	quince	3	8	6	1	3	2
		Nuts	walnut	-	87	87	-	37	37
		Stone fruit	Almond	1	5	3	2	8	5
		Poaceous fruit	Apple	3	20	3	5	33	6
		Stone fruit	Apricot	2	23	3	3	38	5
		Stone fruit	Cherry	2	30	5	3	49	8
		Nuts	Chestnut	16	-	16	26	-	26
		Stone fruit	Damson	1	36	3	2	59	6
		Stone fruit (others)	Fig	-	7	7	-	11	11
		Stone fruit	Greengage	2	8	4	3	13	7
		Nuts	Hazelnut	-	2	2	-	3	3
2022	61	Soft fruit	Khaki	7	-	7	11	-	11
		Poaceous fruit	Medlar	1	2	1	2	3	2
		Soft fruit	Mulberry	-	1	1	-	2	2
		Stone fruit (others)	Olive	-	1	1	-	2	2
		Stone fruit	Peach	1	12	2	2	20	4
		Poaceous fruit	Pear	3	19	3	5	31	6
		Stone fruit	Plum	1	8	2	2	13	3
		Soft fruit	Pomegranate	-	1	1	-	2	2
		Poaceous fruit	Quince	2	6	3	3	10	5
		Nuts	Walnut	-	27	27	-	44	44

Figures

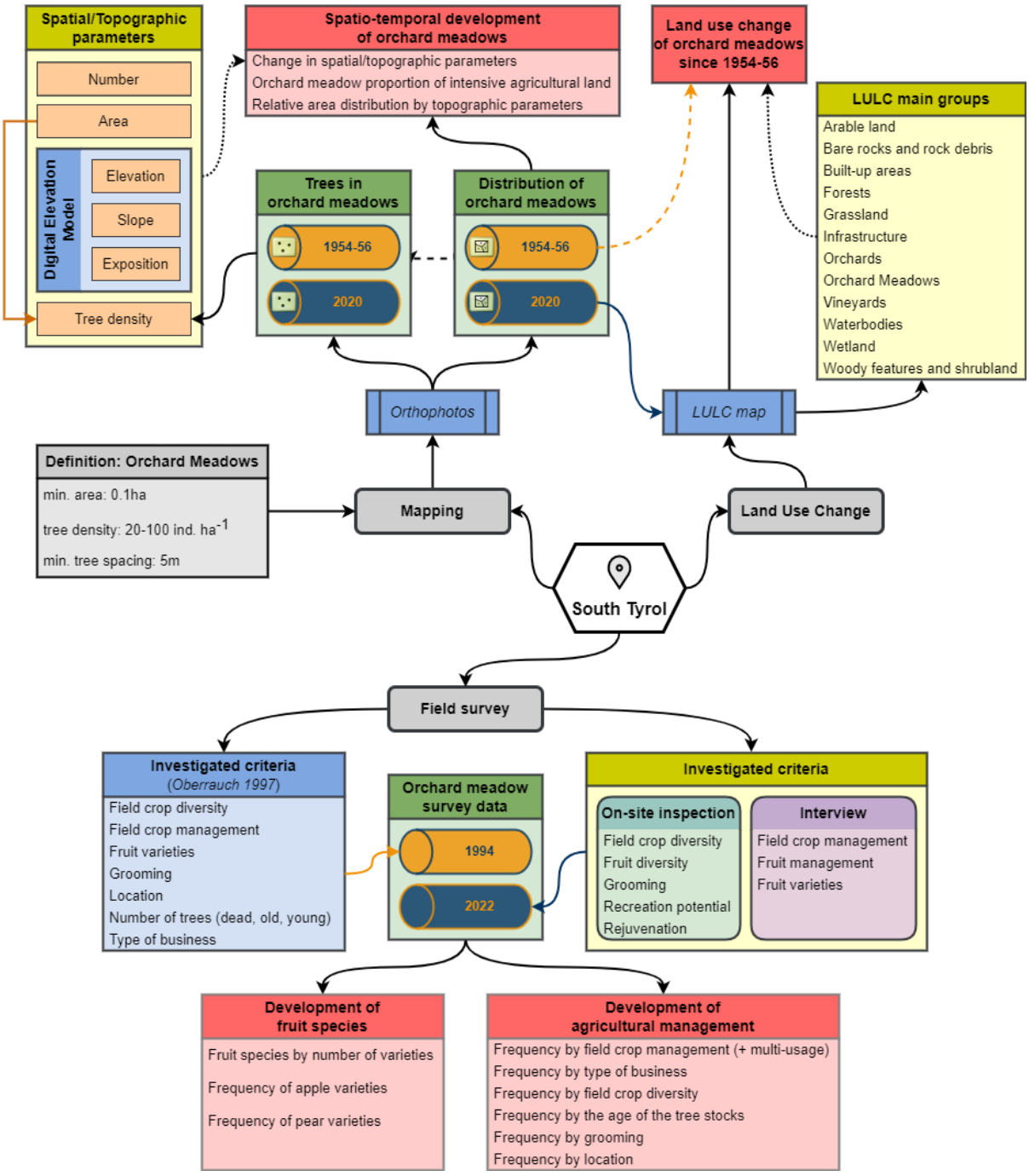

Figure S1: *Overview of the methodology within this study.*

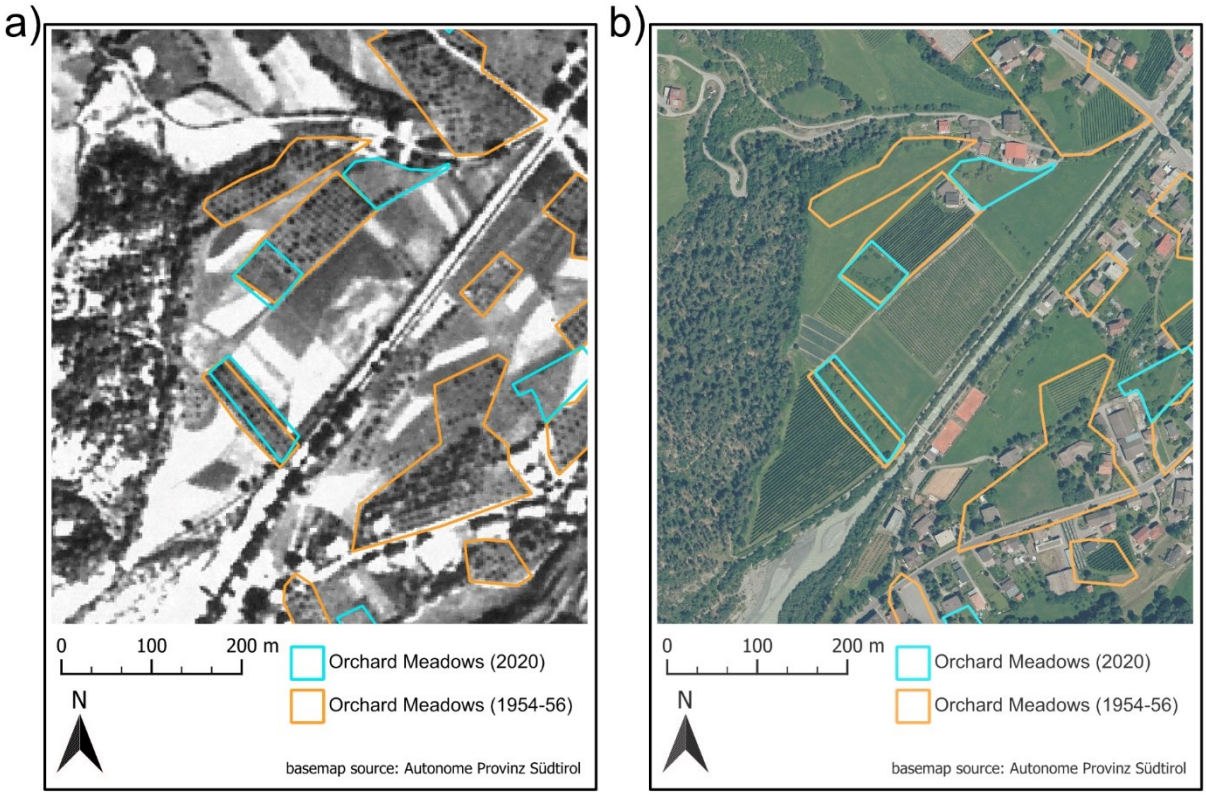

Figure S2: *Example of the mapping approach using orthophotos of 1954-56 (resolution: 1.5x1.5m)* ***[a]*** *and 2020 (resolution: 0.2x0.2m)* ***[b]*** *in detail, at Prad am Stilfserjoch (Vinschgau).*

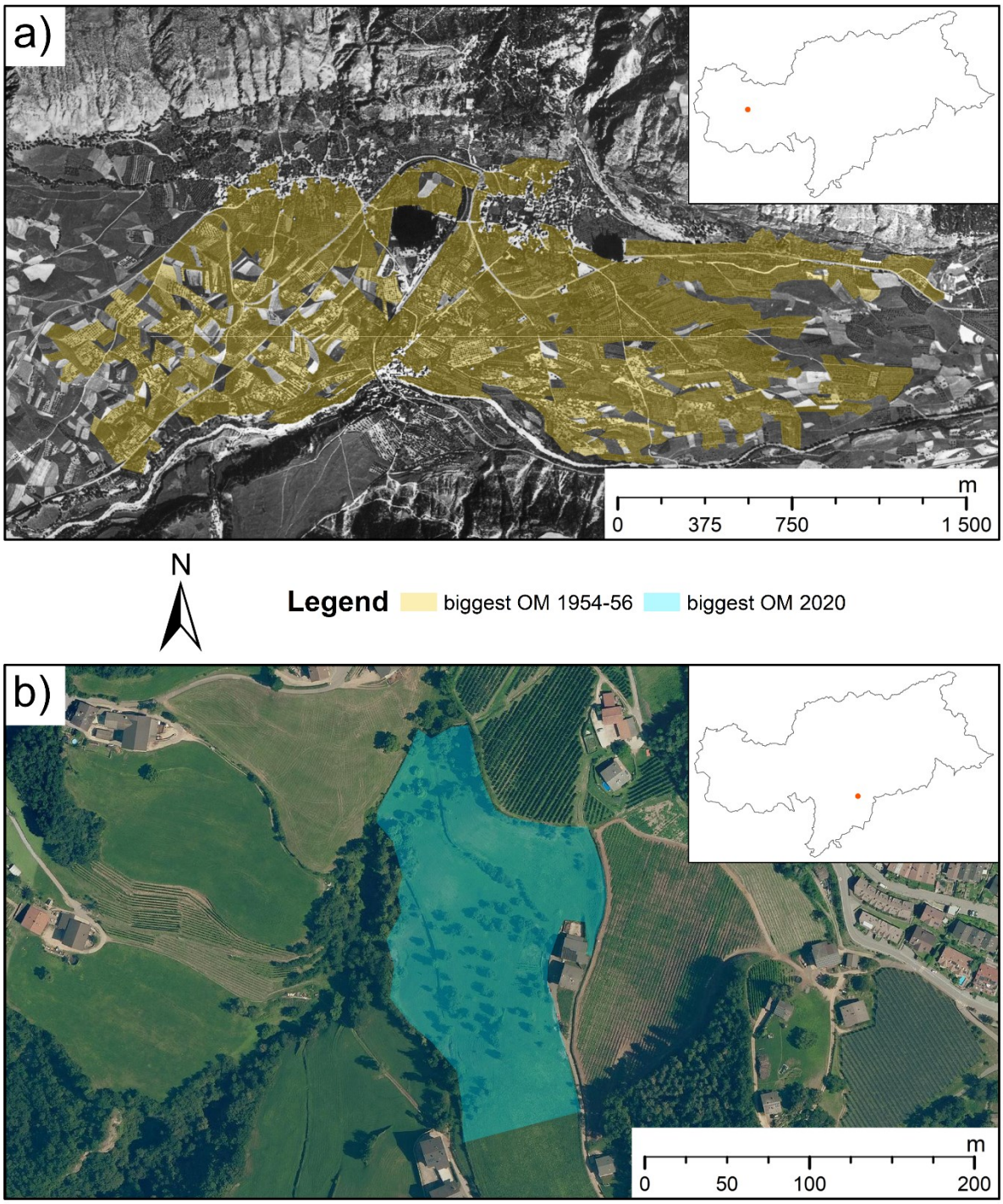

Figure S3: *Biggest contiguous orchard meadow (OM) areas in 1954-56 (Schlanders, Vinschgau)* ***[a]*** *and 2020 (Völs am Schlern, Salten-Schlern)* ***[b]****. basemap source: Autonome Provinz Südtirol.*

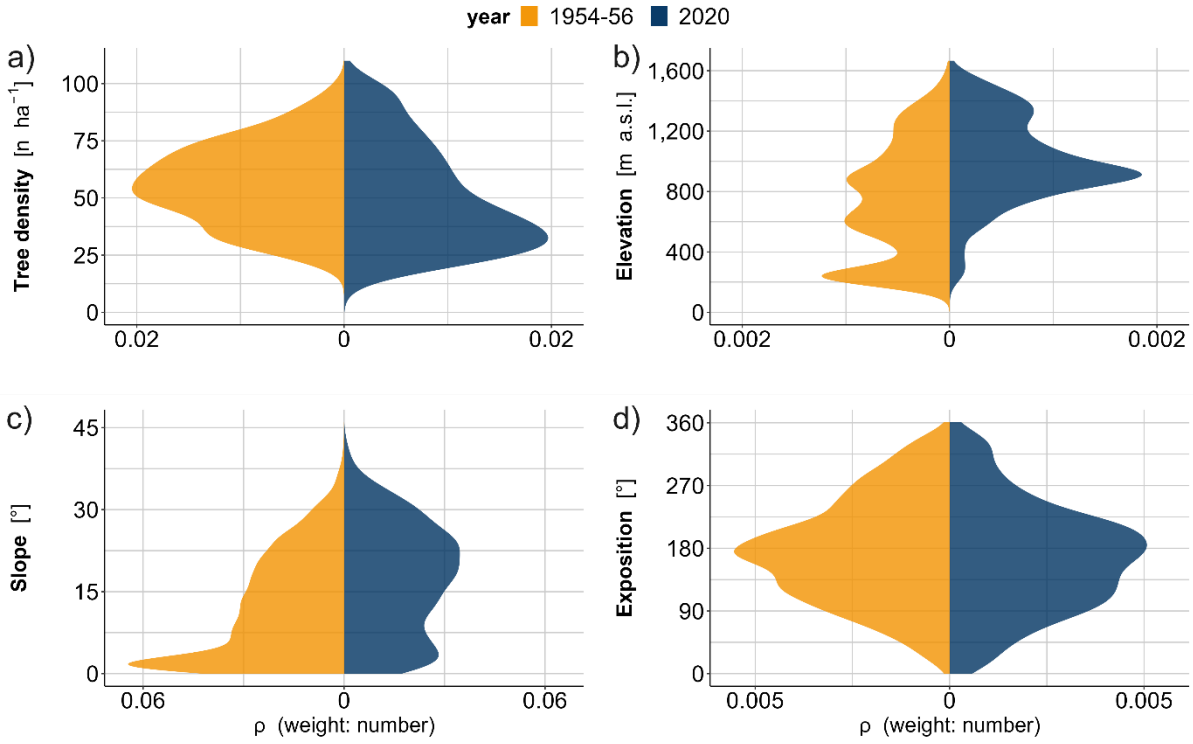

Figure S4: *Temporal Comparison of tree density (only for the district of Vinschgau)* ***[a]****, elevation* ***[b]****, slope* ***[c]****, and aspect* ***[d]*** *of orchard meadows in South Tyrol (Italy), weighted by number.*

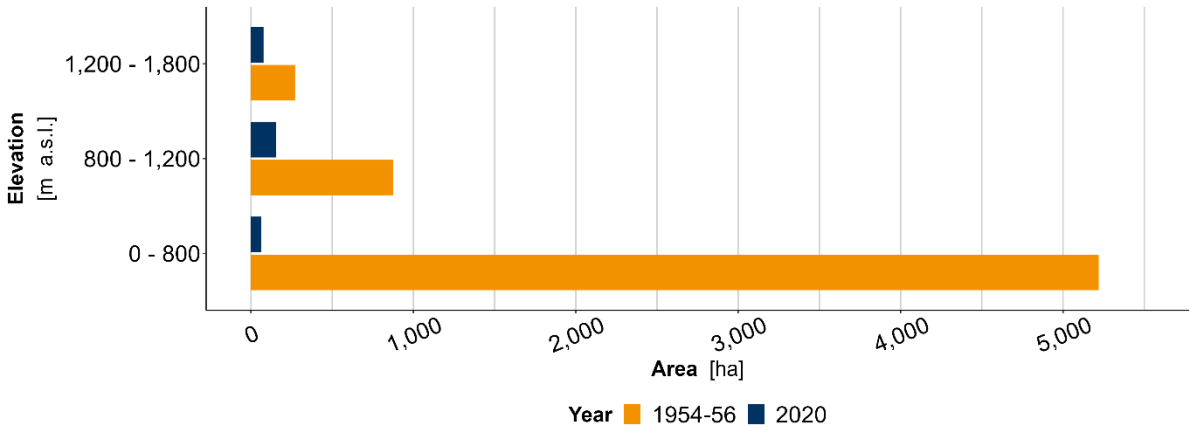

Figure S5: *Total area of orchard meadows in South Tyrol categorized by elevation classes.*

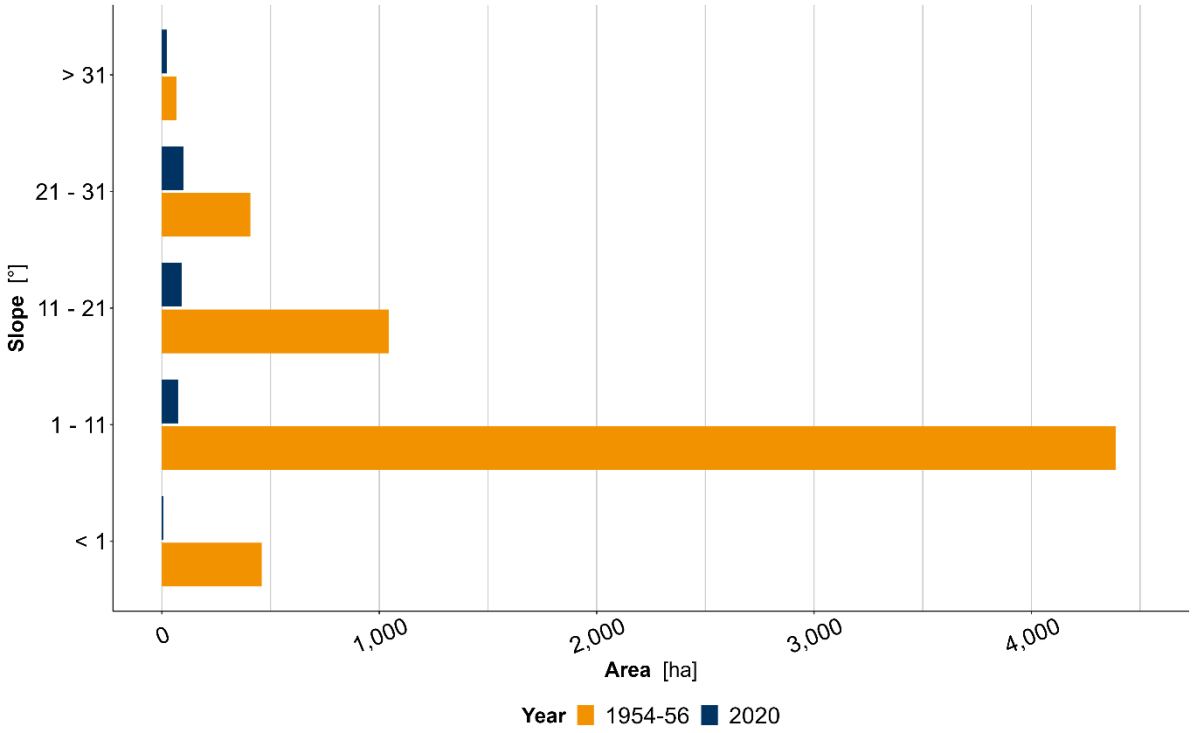

Figure S6: *Total area of orchard meadows in South Tyrol categorized by slope classes.*

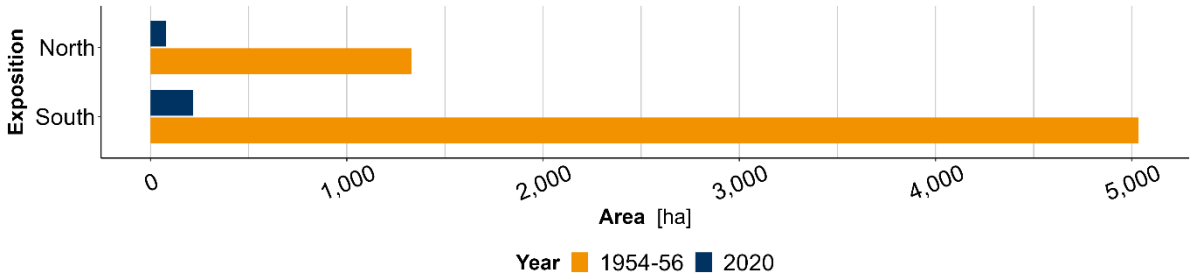

Figure S7: *Total area of orchard meadows in South Tyrol categorized by exposition towards north or south (Tab. S1c).*

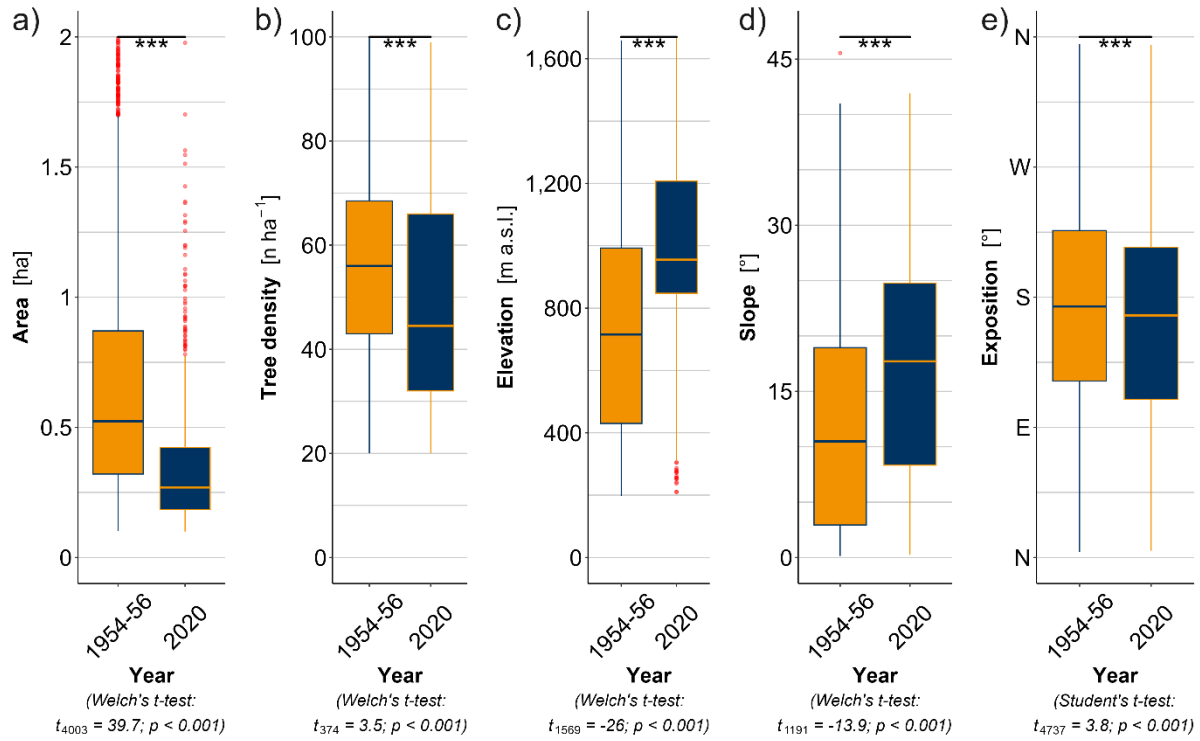

Figure S8: *Orchard meadow distribution in South Tyrol by average area* ***[a]****, tree density* ***[b]****, elevation* ***[c]****, slope* ***[d]****, and exposition* ***[e]****.*

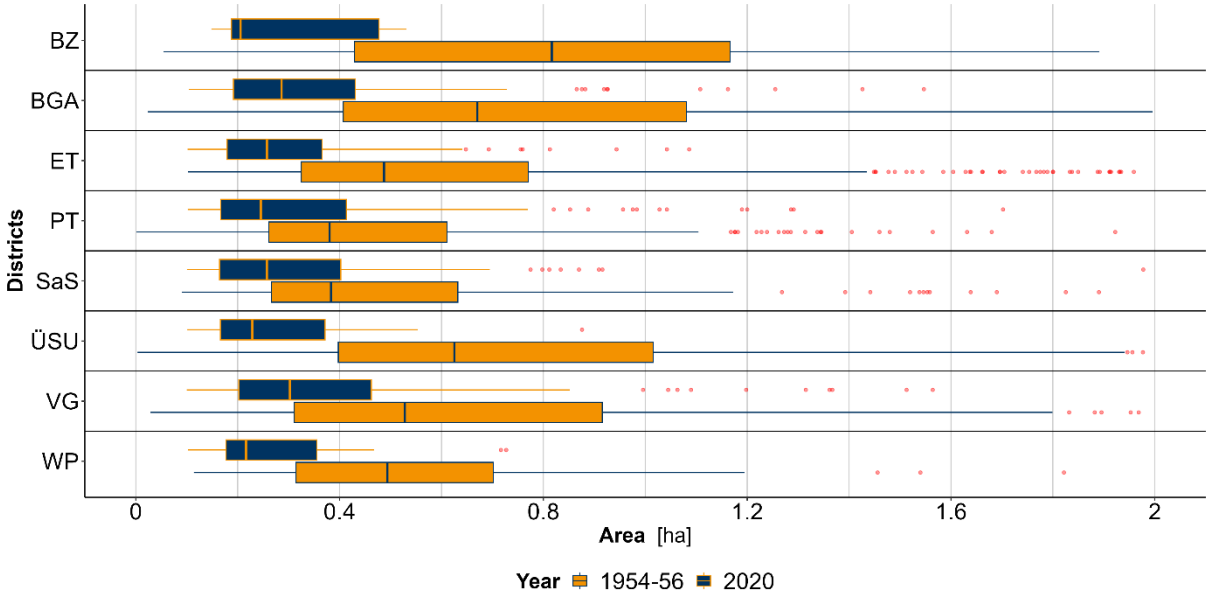

Figure S9: *Orchard meadows in South Tyrol's districts by average area and year.*

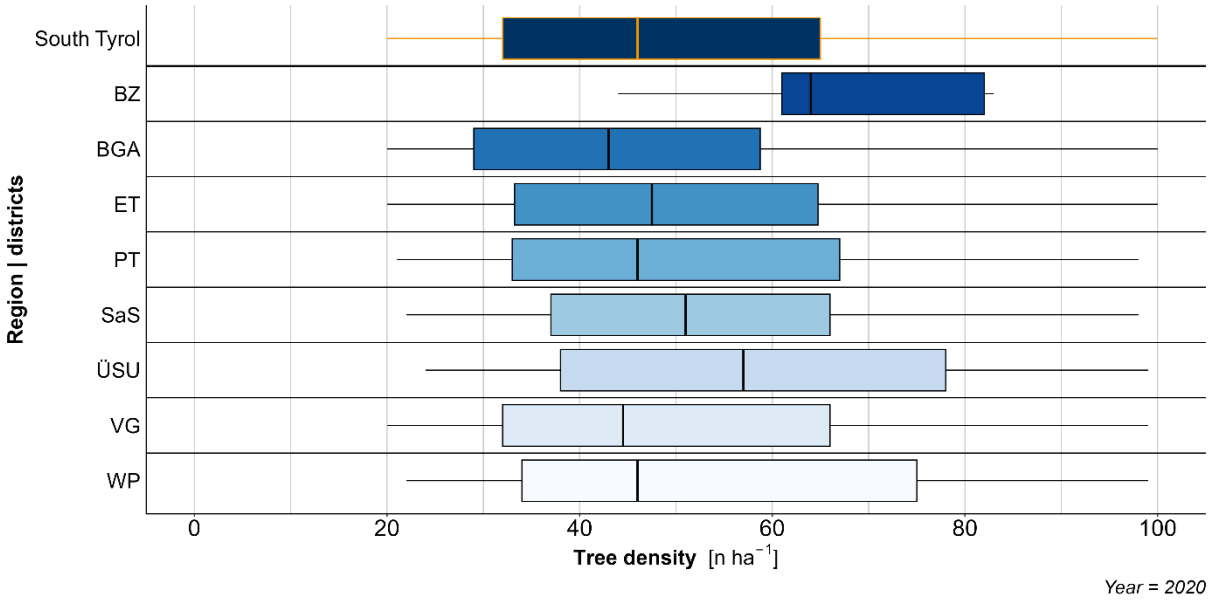

Figure S10: *Orchard meadows in South Tyrol and its districts by average tree density.*

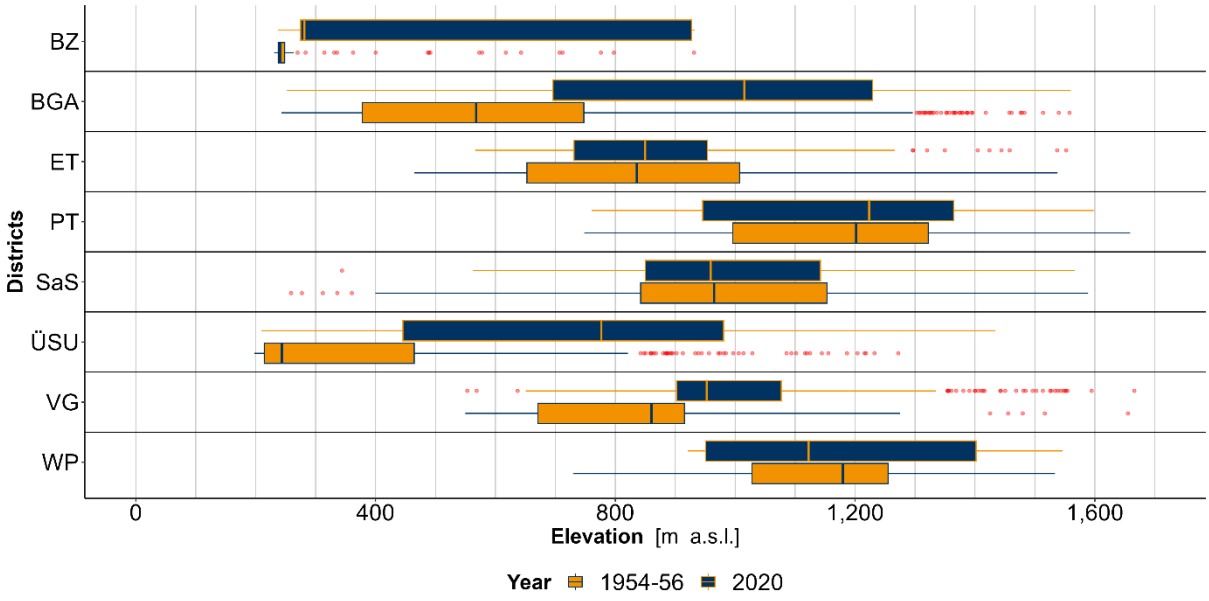

Figure S11: *Orchard meadows in South Tyrol's districts by average elevation and year.*

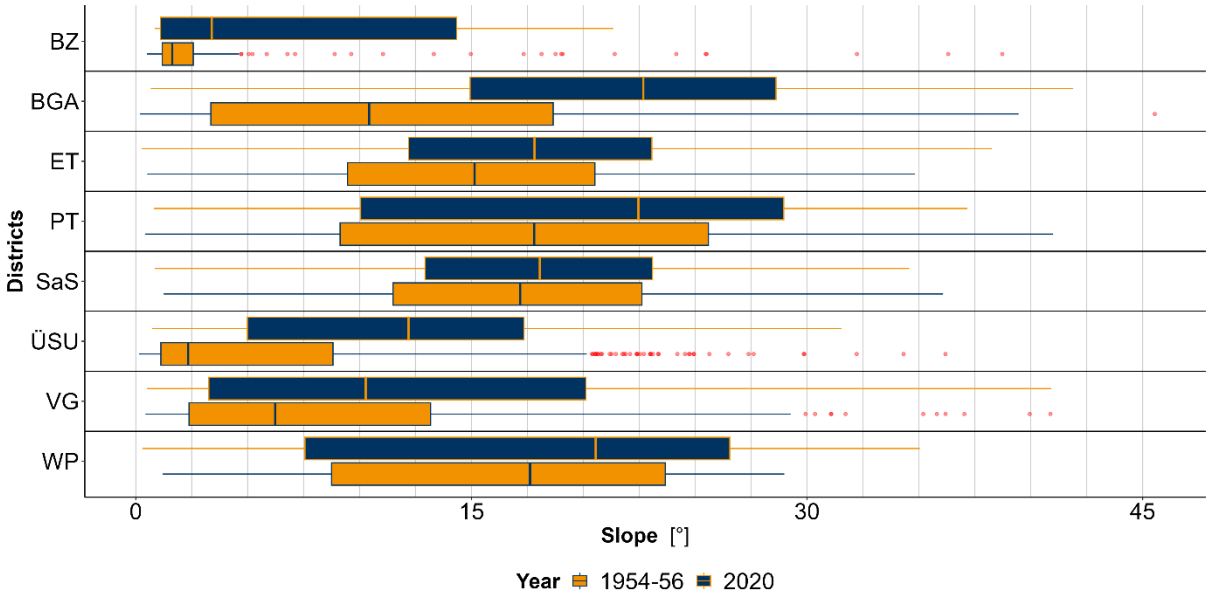

Figure S12: *Orchard meadows in South Tyrol's districts by average slope and year.*

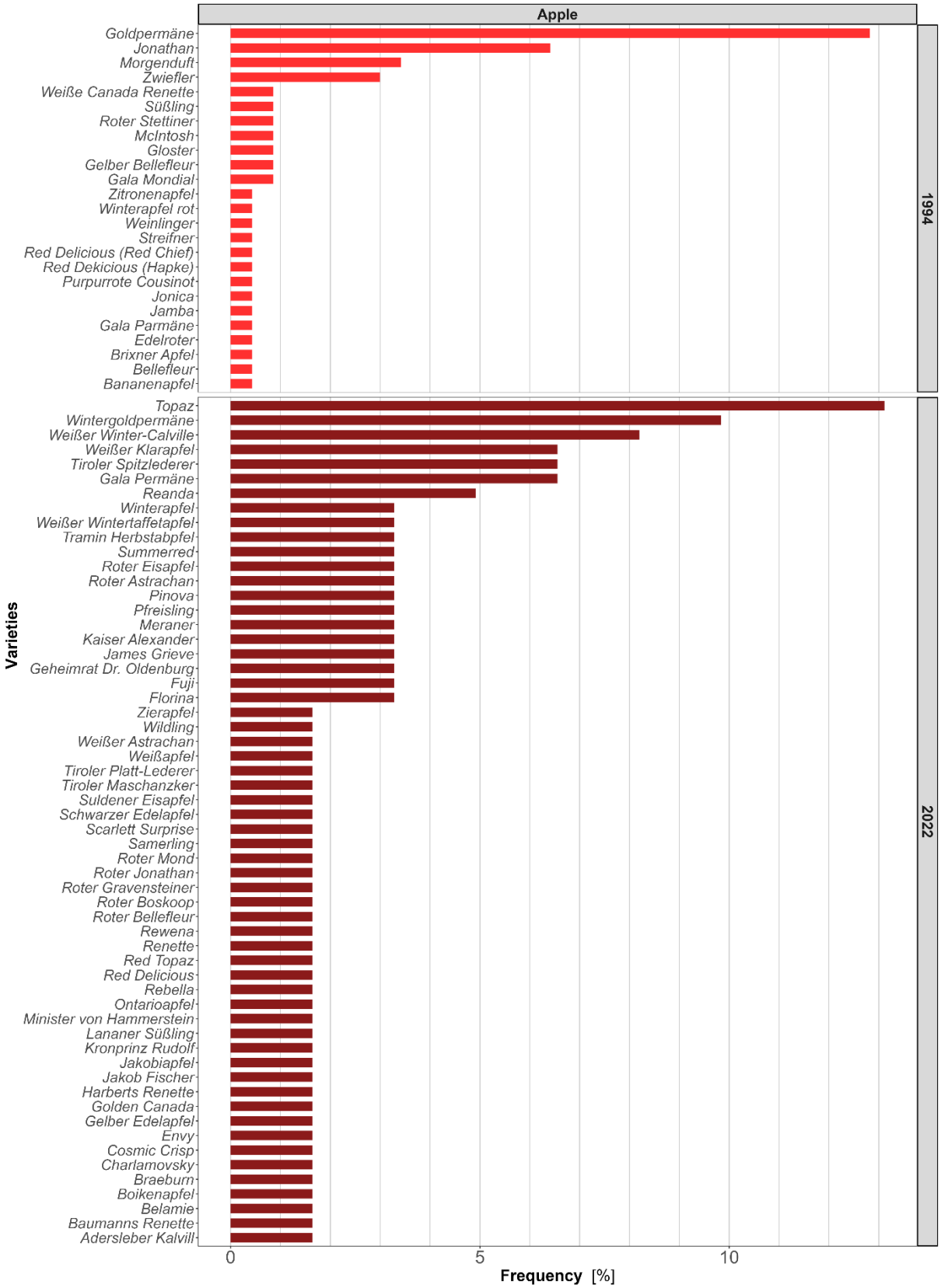

Figure S13: *Apple varieties only found within surveyed orchard meadows in 1994 (Oberrauch 1997) or 2022 by percentage of occurrence.*

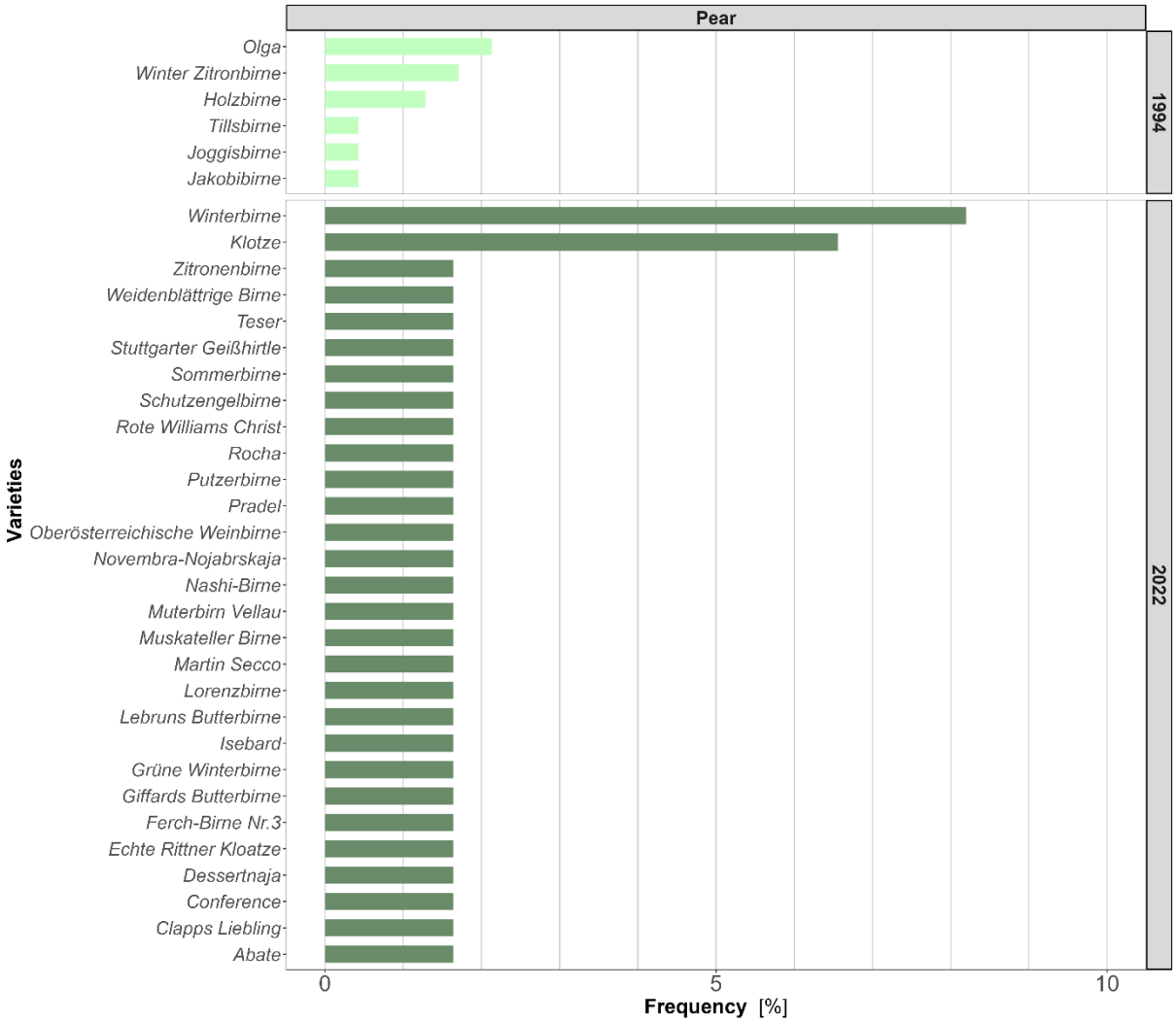

Figure S14: *Pear varieties only found within surveyed orchard meadows in 1994 (Oberrauch 1997) or 2022 by percentage of occurrence.*

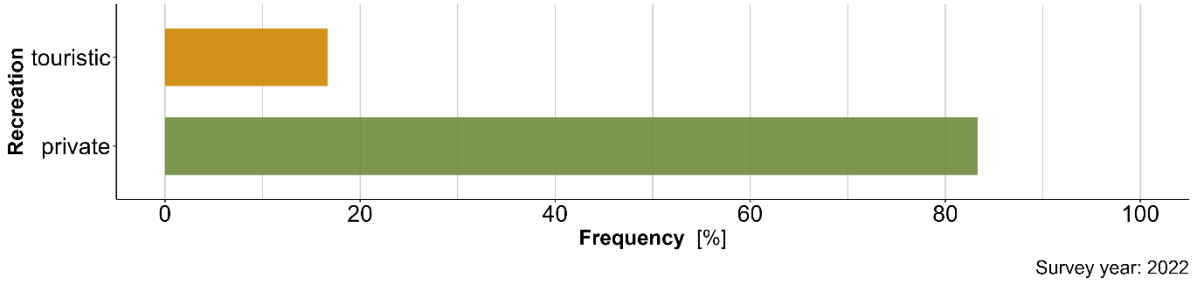

Figure S15: *The field crop management type recreation, categorized by either private or touristic use, in today's orchard meadows.*

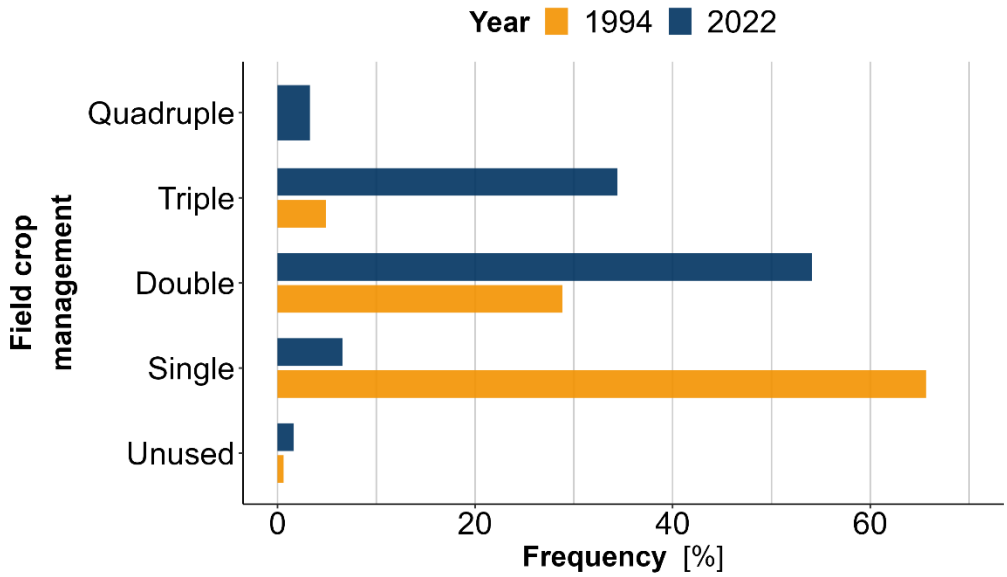

Figure S16: *Frequency of surveyed orchard meadows in 1994 (Oberrauch 1997) and 2022 with no, one, or various applications in field crop management.*

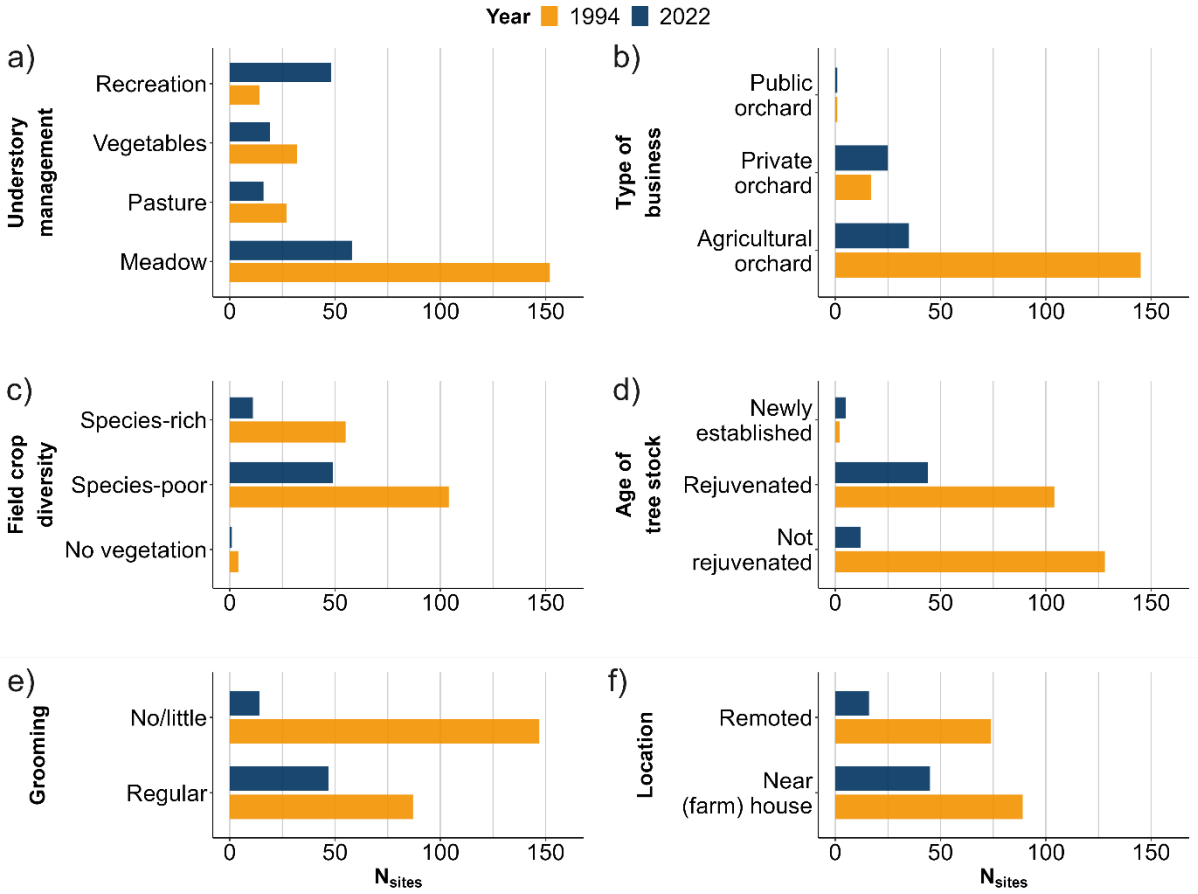

Figure S17: *Comparison of different aspects in agricultural management in 1994 (Oberrauch 1997) and 2022 by number of sites: understory management **[a]**, type of business **[b]**, field crop diversity **[c]**, age of tree stock **[d]**, maintenance **[e]**, and location **[f]**.*