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Once Common, Long in Decline: Dynamics of Traditional Orchards in a Central European Landscape

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Abstract: Traditional orchards are distinctive features of cultural landscapes in Central Europe. Despite their high level of ecological importance, they are in decline, and comprehensive spatial data over broad extents, which could enable a trend analysis, are lacking. We analysed traditional orchard maps from 1952 to 1967 and a map from 2010, generated via aerial image interpretation, for the state of Hesse (ca. 21,115 km^2), which has the second largest share of traditional orchards in Germany. We aimed to (1) quantify long-term orchard dynamics, (2) compare orchard characteristics in terms of topographical, ecological, and socioeconomic factors, and (3) identify key drivers of orchard loss. We found that the number and area of orchards have clearly decreased across Hesse, with varying local and regional patterns. Further, historically old orchards tended to have a larger area, higher shape complexity, and were located closer to settlements, highways, and neighbouring orchards. In contrast, newly established orchards were often found at higher elevations and on steeper slopes. Finally, the three historical orchard hotspots also experienced the most notable losses driven by different factors, namely the expansion of Artificial Surfaces, Residential Buildings, and Agricultural Land. We highlight the importance of such multitemporal spatial data for a wide range of ecological applications, and we encourage the use of novel technologies to support geospatial analyses in the future.

Keywords: traditional orchards; orchard meadows; agroforestry; Streuobstwiese; biodiversity; scattered trees; fruit trees; extensively cultivated landscapes

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1. Introduction

Traditional orchards, also known as orchard meadows, are distinctive features of cultural landscapes in Central Europe [1–4]. They are characterised by fruit trees with high trunks, scattered across meadows or pastures that are managed with low intensity. Unlike high-intensity fruit plantations, traditional orchards exhibit a much wider age distribution and typically feature a diverse array of fruit tree species and varieties that were planted at low densities [4].

Covering a wide range of environmental conditions, traditional orchards play a crucial role in preserving biodiversity at both the local and landscape scales [5–8]. The extraordinary biodiversity found in these traditional agroforestry systems derives from the combination of low-intensity fruit production and grassland management, which creates a high level of structural diversity, allowing for many species to co-exist [4,9]. In Germany, traditional orchard meadows (in German Streuobstwiese) provide a habitat for more than 5000 plant and animal species, and they are regarded as a particular hotspot for biodiversity north of the Alps [3]. They are also important in terms of genetic diversity, representing a reservoir for old domestic animal breeds and fruit tree varieties [10].

Beyond their high value for biodiversity conservation, traditional orchards offer numerous essential ecosystem services and functions. Their complex structure, with the unique combination of a tree and an herbaceous stratum, and the minimal to nonexistent use of chemical fertilisers and pesticides support a wide array of provisioning, cultural, supporting, and regulating services [3,11]. Provisioning services include the production of regional fruits and products derived from fruit such as juices or wines, as well as fodder for domestic animals [12]. Culturally, these traditional orchards contribute to recreation, education, tourism, the landscape's aesthetic value, and the regional identity of people [13–15]. Finally, they contribute to essential regulation and support services such as regulation of the microclimate, carbon sequestration, or a reduction in surface run-off and erosion [16–19]. Therefore, such traditional agroforestry systems could play a vital role in agroecological schemes in Europe [20].

Despite their ability to provide multiple ecosystem services at high levels and their substantial ecological value, orchard meadows are an endangered biotope type in Germany. Following the expansion of fruit trees during the 18th and 19th centuries and the peak of traditional orchards in the mid-20th century, both their quantity and the ecological quality have steadily declined due to the increasingly uneconomical nature of their maintenance [1,3,21]. They have only recently reached protection status at the national level [22]. However, in Germany, no comprehensive spatial data sets exist on the cover and distribution of traditional orchards to estimate the current area or to monitor temporal trends [3]. Although the official data sets available for the country, such as the Digital Landscape Model (DLM) and the Digital Land Cover Model (LBM), include spatially explicit data on traditional orchards, estimates of orchard areas from these sources differ strongly, and many inconsistencies are apparent when compared to external reference maps [3]. While spatial data exist at the federal state level, differences in mapping methodologies often limit their interpretative value [3]. Historical data sets that would enable trend analyses [15,23] are similarly inconsistent [3]. High-quality data sets do exist for twelve so-called model regions in Germany, but these are mostly limited to the district level and cover an area between 10 and 1000 km^2 [3]. To properly analyse the current situation and historical trends in traditional orchards, large-scale data with high spatial resolution, acquired using consistent methodologies, are required, but these are currently only available locally.

The considerable loss of traditional orchards observed during recent decades can be attributed to a variety of socio-ecological factors. These include topographical and edaphic factors such as slope or soil quality, landscape metrics such as parcel size or perimeter–area ratio, and surrogate measures of socio-economic development such as distance to urban settlements or main roads [23]. For example, the case study of Plieninger et al. [23] on orchards in southwestern Germany revealed that distance to urban settlements was the most important factor determining the observed loss of orchard area and the decrease in average patch size. However, temporal patterns and trends in orchard loss might differ regionally due to different environmental and societal contexts and can be attributed to both the intensification of land use and the abandonment of land [24]. In some regions, the abandonment of traditional orchards and subsequent succession towards shrubby vegetation, as well as conversion into forests, could be explained by the long distance to roads and the low cover of settlements and sealed areas, while orchards persisted in other areas, especially upland and in low mountain regions [7]. Therefore, understanding the socio-ecological drivers behind traditional orchard loss requires a comprehensive approach, considering a wide range of attributes and indicators. To accurately assess regional differences and generalise findings, it is essential to use high-resolution data that cover a large spatial extent.

Here, we selected the federal state of Hesse as the study area. Hesse has the second largest share of traditional orchards in Germany [3]. These orchards are an integral part of the cultural landscape, characteristic of the surroundings of many municipalities [12].

They are designated as a protected habitat type [22], with a state-level protection strategy in place [25]. The main hotspots of traditional orchards are predominantly located in the southern part of the state [12,25]. Politically, their ecological relevance was explicitly acknowledged in the latest coalition treaty in Hesse, where, for example, their preferential use for compensation measures is emphasised [26], making them highly relevant for landscape monitoring and planning.

Comprehensive base data for spatio-temporal analyses of traditional orchard properties in Hesse are available. These include spatial data sets on land use and land cover (LULC) [27], data on soil quality [28,29], and a publicly accessible, high-resolution digital elevation model [30], facilitating detailed topographical analyses. Furthermore, traditional orchards were mapped across the entire state in 2010 via a manual interpretation of public aerial imagery [31]. Georeferenced digitised historical aerial photos covering the time span of 1952–1967 have also been made publicly available, but their potential for detailed trend analyses of traditional orchards at a broad spatial extent has yet to be fully utilised (e.g., [32]).

Therefore, the main objectives of this study were to (1) quantify long-term orchard dynamics, (2) compare orchard characteristics from historic and recent datasets in terms of their topographical, ecological, and socioeconomic factors, and (3) identify the key drivers of orchard loss from the local to regional levels for the entire state of Hesse. This information is crucial for the timely development of effective policies to prevent orchard loss and protect ecosystem services.

2. Materials and Methods

2.1. Study Area

The federal state of Hesse is located in Central Germany and has a total area of ca. 21,116 km^2 [33] (Figure 1). Hesse is subdivided into three government districts, namely Kassel (ca. 8291 km^2) in the north, Gießen (ca. 5381 km^2) in the centre, and Darmstadt (ca. 7444 km^2) in the south (referred to as North, Centre, and South, respectively, in the following) (Figure 1). Government districts are major socio-economic regions according to the European Nomenclature of Territorial Units for Statistics (NUTS) and belong to the second NUTS level (NUTS 2) [34]. These government districts are further subdivided into smaller administrative districts (NUTS 3). The latter include rural (Landkreise in German) and urban districts (Kreisfreie Städte). Hesse comprises twenty-one rural and five urban districts. In this study, the government districts are defined at the regional level, while the smaller administrative districts are defined as the local level. The whole state of Hesse has a population of about 6.3 million people, with more than a third living in the Frankfurt–Rhine/Main area in the south of the state [35].

Aside from the highly urbanised parts, such as the Frankfurt–Rhine/Main area, Hesse is characterised by a high share of forests (ca. 42%), especially in the northeast and east, where forests cover up to 50% of the landscape [36]. Intensively used agricultural regions are present in the area, e.g., in the Wetterau district north of Frankfurt [37], where forest cover is low (15%, [36]), as well as peripheral areas with large proportions of non-intensively used grasslands, such as the Lahn–Dill district [38]. The highest mountain, at almost 950 m a.s.l, is located in the Fulda district, west of one of the largest continuous basalt areas (mainly located in the Vogelsberg district [39]).

The climate of Hesse is rather continental. The average annual precipitation ranges between 600 and 800 mm. The lowlands of the Upper Rhine Valley in the south are characterised by an even lower annual rainfall of 500 mm, while at higher elevations, such as in the Vogelsberg district, annual precipitation exceeds 1400 mm [40]. The average annual temperature for the period of 1981–2010 was 8.8 °C [40], showing an increase compared to the time period of 1951–1980, where it was lower, at 8.2 °C [41]. Pronounced variations in annual temperature can be observed, primarily oriented along a north–south gradient, with higher temperatures in the south [40,41]. The Climate Protection Scenario for Hesse predicts that average temperatures will continue to increase, subsequently leading to an increase in exceptionally warm days with temperatures higher than 30 °C [41]. At the same time, the risk of late frost remains, and precipitation patterns are expected to change [42]. In the future, precipitation maxima are more likely to occur in winter than in summer, and the probability of both heavy precipitation and drought events is likely to increase, too [42]. Recent extreme drought events, such as that in 2018, had a noticeable effect on ecosystem conditions across Land Use/Land Cover types in Hesse [43].

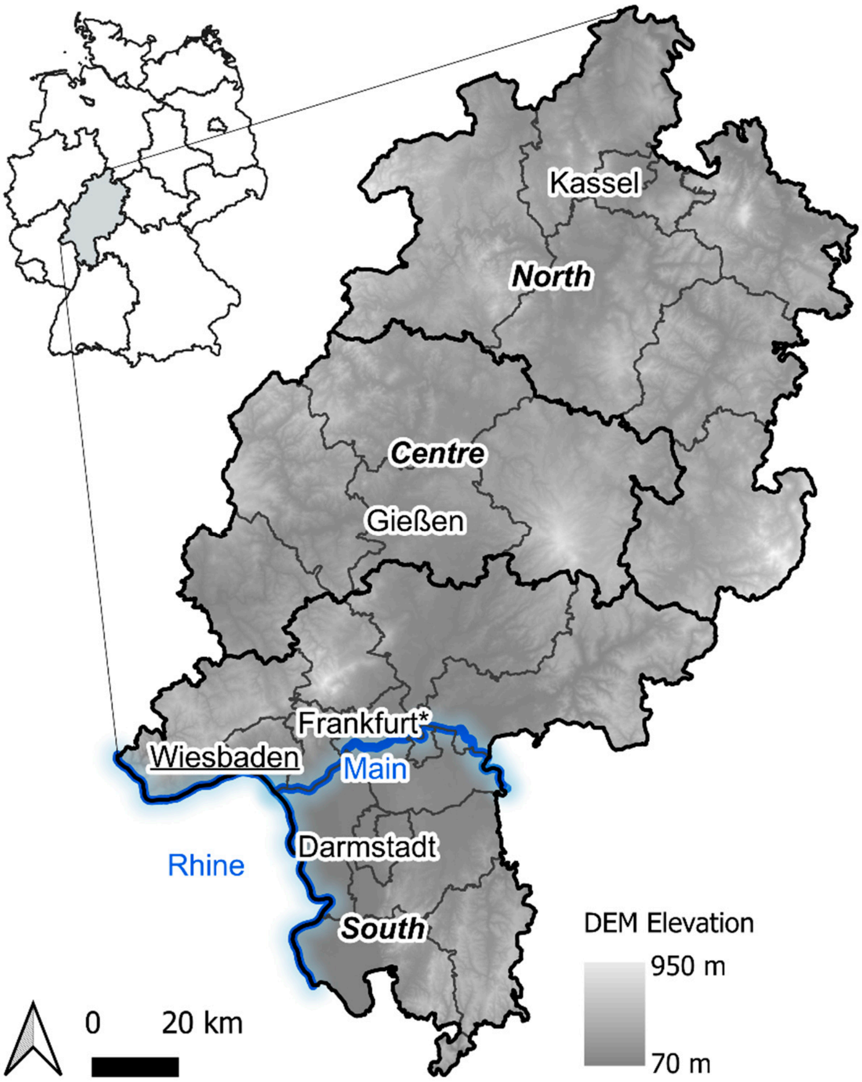


Figure 1. Location of the federal state of Hesse in Central Germany with a digital elevation model (DEM) ranging between 70 and 950 m above sea level in the background. The bold black line delineates the three government districts of Kassel, Gießen, and Darmstadt, which correspond to the regions North, Centre, and South, while the thin black lines delineate the rural and urban districts. The shiny blue lines represent the Rhine and Main rivers, respectively. Wiesbaden (underlined) is the state capital, and Frankfurt (asterisk) is the largest city in Hesse.

2.2. Geospatial Data

The geospatial data analysed in this study comprised spatial information on recent and historic traditional orchard distribution, soil quality, road network, Land Use/Land Cover, and topography (Table 1).

Traditional orchards, together with woody features, tree rows, and tree alleys, were mapped via manual image interpretation of aerial orthophotos from 2008 to 2010 by the Hessian Agency for Nature Conservation, Environment and Geology (HLNUG) for the entire Hesse [31]. These data are available in vector format and are referred to as recent data in the following. Ancillary data for this manual interpretation included cadastral information as well as the results of the statewide biotope mapping [31,44]. The landscape elements were distinguished based on structure, texture, spectral information, size, and shape, and were only mapped outside urban areas [44]. In addition, historical digital aerial images covering the years 1952–1967 are available for almost the whole state of Hesse via the Web Map Service, with only a few data gaps in the northeast near the former border between East and West Germany [45]. Due to the high quality of the historical images, we were able to apply the HLNUG mapping key [44] to also produce maps in vector format via manual image interpretation for traditional orchards in Hesse for the period 1952–1967, referred to in the following as historic data. In addition, the recent and historic vector data were intersected. Therefore, we identified traditional orchards that existed either only in the historic data set and were removed after 1952–1967 (referred to as loss), or only in the recent data set and were established after 1952–1967 (gain), or in both data sets and remained orchards throughout the years (remain) (Table 1). Polygon fragments in the gain, loss, or remain data set resulting from the aforementioned intersection that had a smaller size than the minimum polygon size of the recent and historic data, i.e., 50 m^2, were removed.

For all traditional orchards of these five data sets (recent, historic, gain, loss, remain), we computed the following landscape ecological attributes: Area, Perimeter, Perimeter–Area Ratio, Distance Nearest Orchard, and the Shape Complexity Index [46]. In addition, soil quality was extracted from the yield potential map of the HLNUG [28,29]. The yield potential ranges from 1 (very low) to 5 (very high) and combines information on the usable field capacity of the rooting zone, the effects of groundwater, land use, and base saturation [28]. If an orchard polygon was covered by more than one yield class, the final yield potential class for the respective orchard was computed proportionally (i.e., if 750 m^2 of an orchard was covered by yield potential class 3, and 250 m^2 by class 2, the resulting yield class was 2.75).

The distances from traditional orchards to urban settlements or main roads (Table 1), as surrogate measures of socio-economic development [23], were computed based on the aforementioned orchard maps and vector data on highways (classes autobahn and bundesstrasse) and urban settlements (class siedlung) extracted from the German Digital Landscape Model of Hesse [27]. To analyse the main drivers of orchard decline, LULC information was extracted for the lost orchards based on the German Digital Landscape Model [27] (class objektart) and recoded based on Table S1, resulting in seven LULC classes: Agricultural Land, Artificial Surfaces, Forest, Other Vegetation, Residential Buildings, Water Bodies, and Woody Features. For further analysis, LULC conversion data were aggregated at the local (district) level.

Finally, the topographical attributes Slope, Northness, and Eastness were computed for each traditional orchard based on the 5 m digital elevation model provided by the Hessian Agency for Land Management and Geoinformation (HVBG) [30].

Data were processed using the packages terra (version 1.7–78) [47], sf [48,49] (1.0–16), exactextractr (0.10.0) [50], dplyr (1.1.4) [51], units (0.8–5) [52], and nngeo (0.4.8) [53], and data were tabulated using the packages gtsummary (2.0.1) [54] and gt (0.11.0) [55], in R statistical software (4.4.0) [56]. The Shape Complexity Index was computed using Whitebox Toolbox (2.4.0) [46].

Table 1. Overview of the geospatial data and the derived attributes for each traditional orchard.

Geospatial Data	Derived Attribute for Each Traditional Orchard
Administrative Units [57]	Regional level (NUTS 2): Government Districts; Regions North, Centre, South Local level (NUTS 3): Districts

Table 1. *Cont.*

Geospatial Data	Derived Attribute for Each Traditional Orchard
Maps of Traditional Orchards: Recent (2008–2010) [31,44] and Historic (1952–1967) [this study]	Status: Historic, Recent; Gain, Loss, Remain
	Landscape Ecological Parameters: Area, Perimeter, Perimeter–Area Ratio, Distance Nearest Orchard, Shape Complexity Index
Soil Map [28,29]	Soil Quality: Yield Potential
Digital Landscape Model (Basis-DLM) [27]	Socioeconomic Parameters: Nearest Highway, Nearest Settlement, Land Use/Land Cover (LULC)
Digital Elevation Model (DEM) [30]	Topographical Parameters: Slope, Northness, Eastness

2.3. Data Analysis and Modelling

To produce area-based overviews of historic, recent, gained, lost, and remaining traditional orchards independently of administrative regions, hexagonal grid maps [58] were produced with a cell size of 55.46 km^2. Orchard density per hexagon was computed as orchard area divided by hexagonal cell area.

To compare the attributes of traditional orchards between the regions and between historic and recent, as well as gained, lost, and remaining orchards, first the normality of the data were assessed using Q-Q plots and the Shapiro–Wilk test [59] and the homogeneity of variances was checked using Bartlett's test [60]. The data set was also controlled for missing data and infinite values, which were subsequently removed. We employed nonparametric tests for our analyses because the data did not follow a normal distribution and exhibited unequal variances. The Mann–Whitney U test (p-value ≤ 0.05) was used to compare historical and recent data. For multiple comparisons across different regions (North, Centre, and South) and across different status categories (gain, loss, and remain), we applied the Kruskal–Wallis (KW) test [61] (p-value ≤ 0.05), followed by the Benjamani–Hochberg (BH) correction test [62].

To analyse if differences regarding orchard attributes at the regional level enable the regions to be distinguished in a semi-automated way using machine learning, Random Forest classification models [63] were applied using the orchard attributes as predictors and the three regions as response variables for both historic and recent data. Random Forest is also a powerful machine learning algorithm [64] for ecological applications [65]. To account for potential differences between orchards in the South, an orchard hotspot [12], compared to the other regions, a three-class model with the original response classes and a two-class model, where Centre and North were merged, were calculated for each data set. The data were split into 75% training and 25% test data, preserving class distributions. Models were trained using 10-fold cross-validation with five repeats and the parameter mtry was optimised for overall accuracy using a search grid ranging from one to eleven while the parameter ntree was set to 1000. Model quality was evaluated based on test set data and several accuracy metrics, including Overall Accuracy, Kappa, Sensitivity, Specificity, Positive Predicted Value, Negative Predicted Value, and F1, considering, if applicable, the Prevalence of the data as well as Precision and Recall [66]. In case of a two class-model, accuracy was evaluated based on a confusion matrix of the test set data, as in Table 2. For the three class-model, each class was compared to all other classes in a similar manner, using a "one versus all" approach [66].

Table 2. Confusion matrix of the test set data as a basis for the calculation of the accuracy metrics for the two class-model with the class South and the merged class Centre_North.

	Reference	
Predicted	South	Centre_North
South	A	B
Centre_North	C	D

Based on the confusion matrix in Table 2, the accuracy metrics were calculated as follows, based on [66]:

$$\text{Overall Accuracy} = \frac{A+D}{(A+B+C+D)}, \tag{1}$$

$$\text{Kappa} = \frac{O-E}{1-E}, \quad \textit{where O is the observed accuracy and E is the expected accuracy}, \tag{2}$$

$$\text{Sensitivity} = \frac{A}{(A+C)}, \tag{3}$$

$$\text{Specificity} = \frac{D}{(B+D)}, \tag{4}$$

$$\text{Prevalence} = \frac{(A+C)}{(A+B+C+D)}, \tag{5}$$

$$\text{Positive Predicted Value} = \frac{sensitivity \times prevalence}{((sensitivity \times prevalence) + ((1 - specificity) \times (1 - prevalance)))}, \tag{6}$$

$$\text{Negative Predicted Value} = \frac{(specificity \times (1 - prevalence))}{(((1 - sensitivity) \times prevalence) + ((specificity) \times (1 - prevalance)))}, \tag{7}$$

$$\text{Precision} = \frac{A}{(A+B)}, \tag{8}$$

$$\text{Recall} = \frac{A}{(A+C)}, \tag{9}$$

$$\text{F1} = \frac{2 \times precision \times recall}{(precision + recall)}. \tag{10}$$

The loss rate of traditional orchards between 1952–1967 and 2008–2010 at the local level was calculated as in [23], following [67]:

$$\text{r} = \left(\frac{1}{2009 - 1959.5}\right) \times \ln\left(\frac{Area\ 2009}{Area\ 1959.5}\right) \tag{11}$$

To examine a potential north–south gradient regarding the drivers of orchard loss at the local level, the y-coordinate of each district centre was extracted and correlated against the percentage/area of each LULC class using the Spearman–Rank correlation [68].

Data analysis and modelling was performed using R statistical software (see above) including the packages car (3.1.2) [69] and multcompView (1.4–25) [70]. Violin plots with embedded box plots to examine the orchard attributes were produced using the packages ggplot2 (3.4.2) [71], gridExtra (2.3) [72], ggbreak (0.1.2) [73], and cowplot (1.1.1) [74]. Random Forest modelling was performed using the packages caret (6.0.-94) [66], randomForest (4.7–1.1) [75], doParallel (1.0.17) [76], and corrplot (0.92) [77]. All maps were created in QGIS, version 3.34 "Prizren" LTR [78], and the coordinate reference system for all data was EPSG: 25832—ETRS89/UTM zone 32N.

3. Results

3.1. Long-Term Dynamics of Traditional Orchards at the State Level

At the state level, the density of traditional orchards has strongly decreased over the past 50 to 60 years (Figure 2a,b). Historically, these orchards were concentrated in the South near the Main River and towards the southern border of the state, as well as in the North near the town of Kassel. By 2010, only the southern hotspots remained noticeable, albeit at much lower levels (Figure 2b). These comparably high densities in 2010 were historically common throughout the state (Figure 2a,b). Consequently, both the number and the total area of traditional orchards decreased dramatically, from 66,602 orchards covering 504 km^2 historically (Table S2) to 21,544 orchards covering 117 km^2 in recent times (Table S3). In fact, the number of traditional orchards at the state level in 2010 was almost equivalent to the number of traditional orchards found in the Centre region alone in 1952–1967 (21,568 orchards, Tables S2 and S3). This strong decrease in absolute numbers is actually even higher than that recorded, as the northeastern part of the study area was not covered by the historic imagery (Figure 2a).

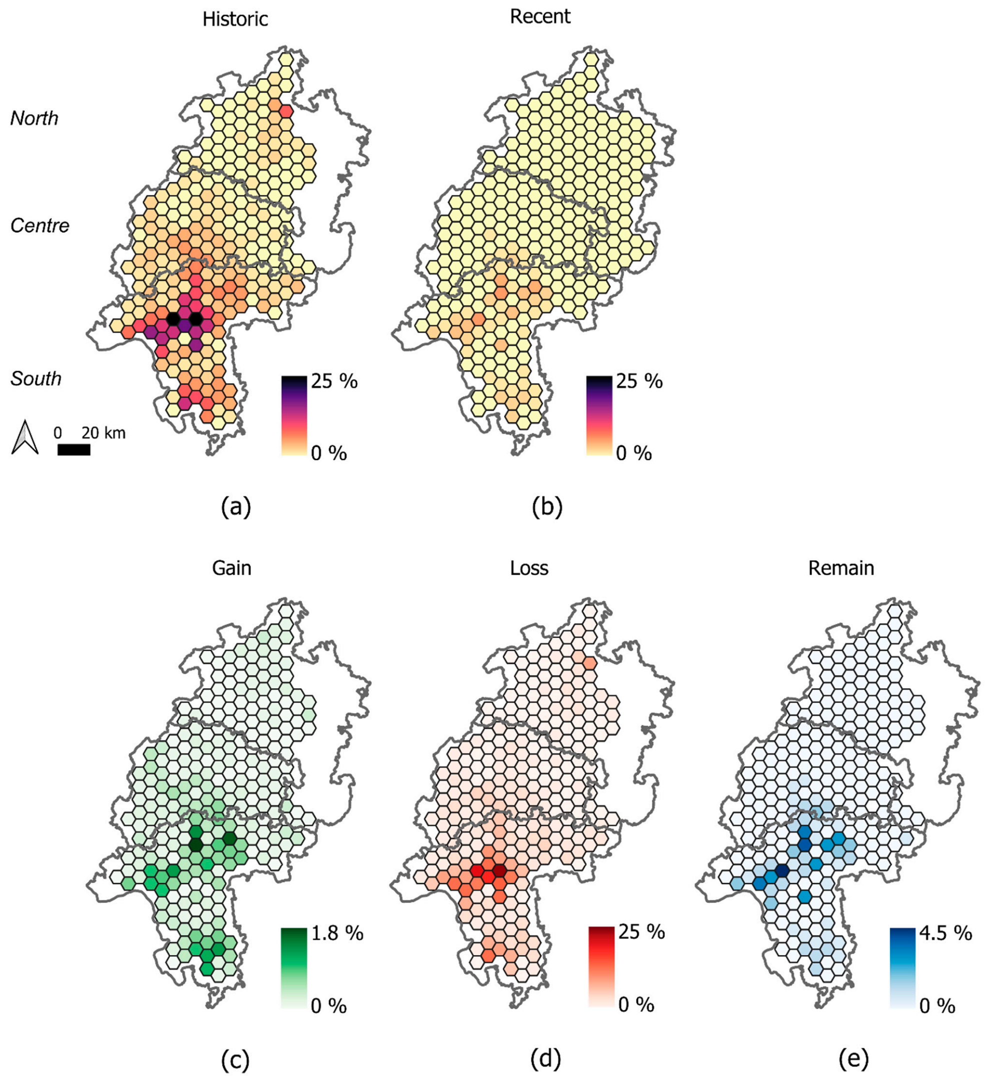


Figure 2. Hexagonal grids of traditional orchard density in Hesse for (**a**) historical (1952–1967), (**b**) recent (2008–2010), (**c**) gained, (**d**) lost, and (**e**) remaining orchards. Grey lines delineate government districts, which define the regional level in this study.

The proportional loss in the number and the area of traditional orchards varied among regions. Statewide, the number of traditional orchards dropped to 32% of historic levels with an even sharper decrease in area, which fell to 23% (Tables S2 and S3). The South mirrored these trends, with reductions to 35% in number and 22% in area (Tables S2 and S3). The North exhibited the lowest proportional decreases, with numbers falling to 46% and area to 33%, while the Centre experienced the most significant losses, with both number and area declining to 23% of historic levels (Tables S2 and S3).

However, there were also slight increases in traditional orchard density, reflecting the establishment of new orchards in locations that historically had different land uses. These gains were primarily observed in the South around two hotspots (Figure 2c), with the largest gains in parts of the main area and near the border of the Centre region, where most of the remaining orchards were located (Figure 2e). Slight increases were also observed in the Centre (Figure 2c). The areas with the largest losses of traditional orchards corresponded to the historical hotspots in both the North and South (Figure 2a,d).

In summary, the loss of traditional orchards occurred all over the state, though the patterns of decline varied by region. Pronounced losses occurred near historical hotspots, with only the South retaining some of these historic hotspots in recent imagery, due to a relatively high number of remaining and newly established traditional orchards. Meanwhile, the North showed generally low densities. The locations of hotspots have shifted slightly, particularly in the South towards the Centre region, where a relatively high proportion of historical orchards persisted. In addition to the hotspot in the South, slight gains were also observed in large parts of the Centre, highlighting the regional differences in orchard dynamics.

3.2. Characteristics of Traditional Orchards at Regional Level

The attributes of orchards differed significantly between regions, with the exception of the exposition-related parameters Northness and Eastness, where no significant differences were observed between Centre and South, and North and Centre, respectively (Figure 3). In all regions, historic traditional orchards differed significantly from recent ones across all 12 tested parameters, although the direction of these changes varied between the regions (Figure 3, Tables S2 and S3). For instance, all ecological landscape attributes, namely Area, Perimeter, Perimeter–Area Ratio, and Shape Complexity Index, were generally lower in recent orchards compared with historic ones across nearly all regions (Figure 3, Tables S2 and S3). The only exceptions were an increase in Perimeter in the North, and a rise in median Area from 2223 m^2 to 2655 m^2 in the Centre (Tables S2 and S3). In contrast, all distance-related attributes, namely Distance Nearest Orchard, Distance Settlement, and Distance Highway, along with the topographical attributes Slope and Elevation, increased (Tables S2 and S3). Thus, in 2010, traditional orchards were located, on average, at higher elevations and on steeper slopes compared to 1952–1967 (Figure 3, Tables S2 and S3). The exposition-related attributes showed diverging trends: while exposition shifted slightly towards the northeast in the North and South, it shifted towards the southwest in the Centre (Tables S2 and S3). Soil quality remained relatively stable, with a slight decline observed in the South, suggesting that recent orchards are, on average, located on less fertile soils compared to 1952–1967 (Tables S2 and S3).

The comparisons of attributes among newly established (Gain), lost (Loss), and remaining (Remain) orchards revealed a consistent pattern (Figure 4, Tables S4–S6). All attributes showed significant differences, except for the exposition-related parameters. Specifically, Northness showed significant variation only in the North, while Eastness did not differ at all across regions (Figure 4). All ecological landscape parameters differed significantly between lost orchards and both newly established and remaining orchards (Figure 4, Tables S4–S6). Lost orchards had, on average, a larger Area, higher Perimeter values, and a greater Shape Complexity, while Distance Nearest Orchard and Perimeter–Area Ratio was consistently lower (Figure 4, Tables S4–S6). Additionally, lost orchards tended to be closer to highways, situated on moderately steep slopes, and, with the exception of the South, facing towards the south (Figure 4, Tables S4–S6).

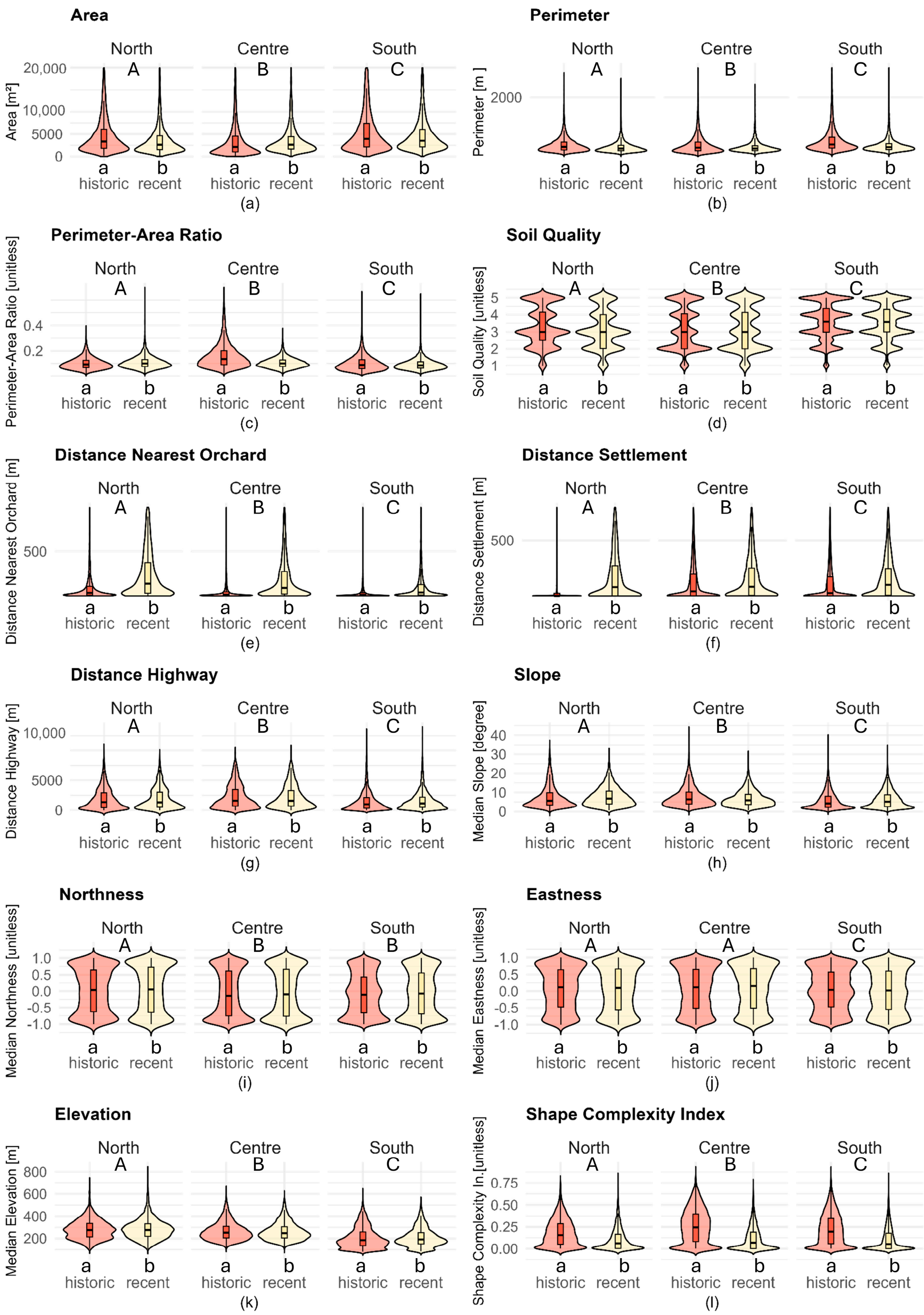


Figure 3. Comparison of the twelve computed traditional orchard attributes between the three regions and between the historical (1952–1967, red) and the recent (2008–2010, yellow) data. The capital letters above the violin plots indicate significant differences in the comparisons between the regions for both historic and recent data, and the small letters below the violin plots indicate significant differences in the comparisons between historic and recent data within each region (p-value ≤ 0.05). Orchard attributes include (**a**) Area, (**b**) Perimeter, (**c**) Perimeter-Area-Ratio, (**d**) Soil Quality, (**e**) Distance Nearest Orchard, (**f**) Distance Settlement, (**g**) Distance Highway, (**h**) Slope, (**i**) Northness, (**j**) Eastness, (**k**) Elevation, and (**l**) Shape Complexity Index.

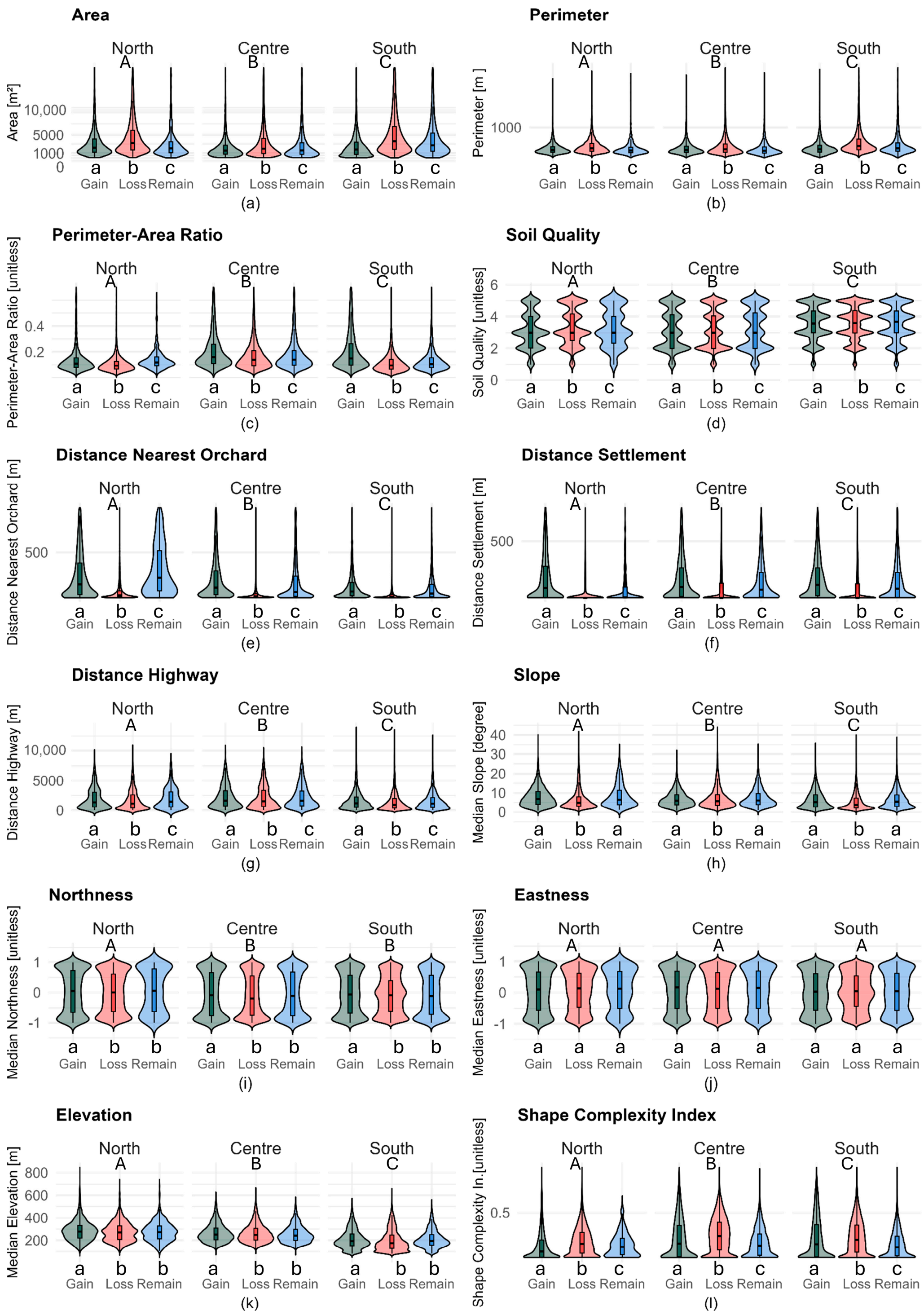


Figure 4. Comparison of the twelve computed traditional orchard attributes of the three regions and between the newly established or gained (green), lost (red), and remaining (blue) traditional orchards for the time spans 1952–1967 and 2008–2010. The capital letters above the violin plots indicate the significant differences in the comparisons between the regions of gained, lost, and remaining orchards, and the small letters below the violin plots indicate significant differences in the comparisons between gained, lost, and remaining orchards within each region (p-value ≤ 0.05). Orchard attributes include (**a**) Area, (**b**) Perimeter, (**c**) Perimeter-Area-Ratio, (**d**) Soil Quality, (**e**) Distance Nearest Orchard, (**f**) Distance Settlement, (**g**) Distance Highway, (**h**) Slope, (**i**) Northness, (**j**) Eastness, (**k**) Elevation, and (**l**) Shape Complexity Index.

In contrast, newly established orchards were characterised by a relatively high Perimeter–Area Ratio and both a greater Distance Nearest Orchard and Distance Highway (except for the North). These orchards also showed consistently higher Distance Settlement and were slightly more oriented towards the north, with a general trend towards orchards being located at higher elevations (Figure 4, Tables S4–S6). Soil quality was moderate for all orchards, with slightly better soil quality in the South (Figure 4, Tables S4–S6).

Comparing the remaining with the newly established orchards, the most notable differences were related to Area, Distance Nearest Orchards, and Distance Settlement. Newly established orchards were slightly (Centre) or clearly (South) smaller than the older orchards from 1952 to 1967, while in the North they were actually about 10% larger. Similarly, the distances between remaining orchards were, on average, smaller in the Centre and in the South, but clearly larger in the North compared to the distances between the newly established orchards. In contrast, the distance to settlements showed consistent patterns. The remaining orchards in all regions were located closer to settlements than the newly established orchards, with minimum distances for the older orchards occurring in the North and maximum distances occurring in the South (Figure 4, Tables S4–S6).

In addition to the observed regional patterns in traditional orchard dynamics (Figure 2), we also found significant differences in orchard attributes between regions (Figures 3 and 4). However, the RF model using these orchard attributes as predictors to classify orchards as either North, Centre, or South did not reveal such differences in the historic or in the recent data set (Tables S9–S12). The three-class model yielded rather moderate test set accuracies, with an overall accuracy of 0.71 and 0.64, a Kappa value of 0.47 and 0.41, and an F1 ranging between 0.40 and 0.79 and 0.49 and 0.79 for the historic (Table S9) and the recent (Table S10) data set, respectively. The per-class accuracies (Tables S9 and S10) and the confusion matrices (Tables S11 and S12) indicated higher classification accuracies for the South, but lower accuracies for the Centre, and particularly for the North.

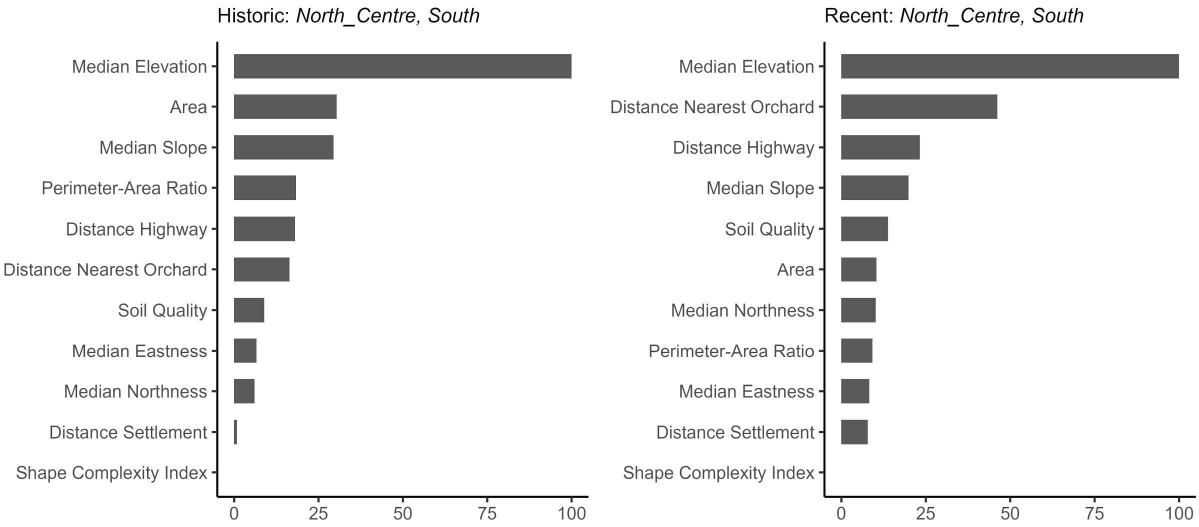
In contrast, the two class-model, which discriminated between the South and a merged Centre_North class, resulted in higher test set accuracies, with Kappa values ranging between 0.52 and 0.54 and all other metrics between 0.72 and 0.80 (Table 3). The two-class classification showed a good model fit for both the historic and the recent data set, with F1 scores of 0.78 and 0.79 (Table 3), respectively. This indicated balanced errors (see also the confusion matrices in Tables S7 and S8), despite the high prevalence of the South class and, thus, imbalanced data sets. Therefore, traditional orchards in the South differ from those in the Centre and in the North in both the historic and recent years.

Table 3. Accuracy metrics of the two-class Random Forest classification model comparing traditional orchards in the South with those in the North and Centre for both (**a**) historic and (**b**) recent data.

Accuracy Metric	Historic	Recent
Overall Accuracy	0.77	0.77
Kappa	0.54	0.52
Sensitivity	0.76	0.80
Specificity	0.77	0.72
Pos. Pred. Value	0.80	0.78
Neg. Pred. Value	0.73	0.74
F1	0.78	0.79

The RF models were optimised for the mtry parameter and overall accuracy. The optimal mtry value for the RF models based on historical data were lower (4) than those based on recent data (7). Variable importance followed this pattern (Figures 5 and S1), and despite significant differences between almost all attributes (Figure 3, Tables S2 and S3), variable importance differed. In the two-class models, the selected predictors had similar ranks for both the historic and recent datasets. Median Elevation emerged as the most important variable and Median Slope also had high importance. Conversely, the Shape Complexity Index, Median Eastness, and Soil Quality were less important. The importance of other predictors differed between the historic and recent datasets. While Perimeter-Area

Ratio and Area were more important in models based on the historical data, all distance-related predictors (Distance Nearest Orchard, Distance Highway, Distance Settlement) were more important in recent years.



(**a**) (**b**)

Figure 5. Variable importance of the two-class Random Forest classification model comparing traditional orchards in the South with those in the North and Centre for both (**a**) historic and (**b**) recent data.

3.3. Key Drivers of Traditional Orchard Loss at the Local Level

The dynamics and drivers of the conversion of traditional orchards to other land use types varied between regions and at the local level (Table 4, Figure 6). The lowest historical area of orchard cover for a rural district was found in the North (Waldeck–Frankenberg, Table 4), while the highest area of historical orchard cover, together with the lowest proportional loss, was located in the South. In the Wetterau district, 41% of the historical 43.13 km^2 of orchard area remained by 2010, with an annual loss rate of 1.83% (Table 4, Figure 6), accompanied by relatively high densities and slight gains due to newly established traditional orchards (Figure 2). At the same time, the district with the highest proportional loss was also located in the South. In the Rheingau–Taunus district, only 10% of the historical 18.96 km^2 of orchards remained by 2010, with an annual loss rate of 4.68% (Table 4, Figure 6), the second highest loss rate after the urban district of Kassel (8.22) in the North. The median loss rate for Hesse at the district level was 3.37%, with a standard deviation of 1.31.

Table 4. Overview of traditional orchard conversion into other Land Use/Land Cover (LULC) types including loss rate per district ordered by region as well as correlation along a South–North gradient. Urban districts were always specified, rural districts only if they shared the same name with an urban equivalent. The main drivers included Artificial Surfaces (Artif. Surfaces), Residential Buildings (Resid. Build.) and Agricultural Land (Agri. Land). Other Veg. = Other vegetation. Minimum (except Water Bodies) and maximum values (regarding percentages) are in bold and highlighted in grey.

	Area Traditional Orchards				LULC Conversion [km^2] ([%])							
District	Historic [km^2]	Recent [km^2]	Ratio R/H [%]	Loss Rate [%]	Agri. Land	Artif. Surfaces	Forest	Other Veg.	Resid. Build.	Water Bodies	Woody Features	Main Drivers [%]
North												
1 Kassel (rural)	13.81	3.39	25	2.84	2.79 (21)	3.15 (24)	0.68 (5)	0.57 (4)	5.55 (42)	0.01 (0)	0.47 (4)	87
2 Kassel (urban)	8.99	**0.15**	**2**	**8.22**	**0.24 (3)**	2.46 (27)	**0.03 (0)**	0.26 (3)	**5.81 (65)**	0 (0)	0.21 (2)	**94**
3 Schwalm-Eder	16.19	2.11	13	4.12	3.50 (22)	5.39 (34)	0.31 (2)	0.40 (3)	5.08 (32)	0.04 (0)	1 (6)	89
4 Waldeck-Frankenberg	10.2	1.93	19	3.37	2.88 (30)	3.10 (32)	0.38 (4)	0.22 (2)	2.62 (27)	0.01 (0)	0.47 (5)	89

Table 4. *Cont.*

	Area Traditional Orchards				LULC Conversion [km^2] ([%])							
District	**Historic [km^2]**	**Recent [km^2]**	**Ratio R/H [%]**	**Loss Rate [%]**	**Agri. Land**	**Artif. Surfaces**	**Forest**	**Other Veg.**	**Resid. Build.**	**Water Bodies**	**Woody Features**	**Main Drivers [%]**
Centre												
5 Gießen	26.11	8.15	31	2.35	7.74 (36)	4.18 (20)	0.76 (4)	0.35 (2)	6.58 (31)	0.02 (0)	1.63 (8)	87
6 Lahn–Dill	20.26	5.04	25	2.81	5.09 (28)	3.41 (19)	**1.28 (7)**	0.29 (2)	6.45 (35)	0.02 (0)	**1.88 (10)**	**81**
7 Limburg–Weilburg	16.68	2.55	15	3.79	4.82 (30)	3.17 (20)	**1.13 (7)**	0.39 (2)	4.86 (31)	0.01 (0)	1.48 (9)	**81**
8 Marburg–Biedenkopf	14.97	2.78	19	3.40	3.30 (24)	4.03 (29)	0.57 (4)	0.23 (2)	4.79 (34)	0 (0)	0.98 (7)	87
9 Vogelsberg	12.65	2.21	17	3.52	3.97 (33)	3.98 (33)	0.26 (2)	0.15 (1)	**2.85 (24)**	0 (0)	0.75 (6)	90
South												
10 Bergstraße	38.32	8.91	23	2.95	**17.93 (53)**	4.34 (13)	1.28 (4)	0.47 (1)	8.47 (25)	0.01 (0)	1.48 (4)	90
11 Darmstadt (urban)	**3.50**	0.75	21	3.12	0.83 (27)	0.84 (27)	0.08 (3)	0.11 (4)	1.00 (33)	0 (0)	0.19 (6)	88
12 Darmstadt-Dieburg	21.76	5.03	23	2.96	7.60 (39)	3.69 (19)	0.37 (2)	0.40 (2)	6.34 (33)	0.01 (0)	1.05 (5)	91
13 Frankfurt a. M. (urban)	37.21	3.03	8	5.07	5.14 (14)	**17.64 (48)**	0.16 (0)	1.41 (4)	10.62 (29)	0.08 (0)	1.65 (4)	91
14 Groß-Gerau	19.75	2.97	15	3.83	7.62 (39)	3.66 (19)	0.77 (4)	**1.57 (8)**	4.90 (25)	**0.15 (1)**	0.75 (4)	83
15 Hochtaunus	23.98	4.01	17	3.61	5.84 (27)	5.01 (23)	0.71 (3)	0.32 (2)	8.91 (41)	0 (0)	0.68 (3)	92
16 Main-Kinzig	38.34	8.78	23	2.98	9.68 (28)	7.02 (21)	2.08 (6)	0.74 (2)	12.09 (35)	0.03 (0)	2.44 (7)	84
17 Main-Taunus	31.72	6.38	20	3.24	8.60 (31)	5.47 (19)	1.10 (4)	0.95 (3)	10.09 (36)	0.03 (0)	1.91 (7)	86
18 Odenwald	21.50	6.95	32	2.28	**9.57 (53)**	2.92 (16)	0.42 (2)	**0.14 (1)**	4.35 (24)	0 (0)	0.55 (3)	**94**
19 Offenbach (rural)	18.63	3.51	19	3.37	4.62 (28)	4.18 (26)	0.65 (4)	0.42 (3)	5.16 (32)	0.07 (0)	1.25 (8)	85
20 Offenbach (urban) (urban)	5.37	0.29	5	5.91	0.37 (7)	**2.52 (48)**	0.05 (1)	0.17 (3)	2.04 (39)	0 (0)	**0.13 (2)**	93
21 Rheingau-Taunus	18.96	1.87	10	4.68	8.16 (43)	2.86 (15)	1.12 (6)	0.57 (3)	5.00 (26)	0.01 (0)	1.21 (6)	85
22 Wetterau	**49.13**	**19.90**	**41**	**1.83**	15.05 (41)	7.50 (21)	1.09 (3)	0.79 (2)	9.91 (27)	0.03 (0)	2.21 (6)	89
23 Wiesbaden (urban)	27.29	5.08	19	3.40	4.93 (21)	8.03 (34)	0.50 (2)	0.44 (2)	8.39 (35)	0 (0)	1.36 (6)	90
Correlation along south–north gradient					−0.42	0.37	0.17	0.05	0.32	−0.22	0.17	−0.15

The three main drivers of traditional orchard loss, namely conversion to Residential Buildings, Artificial Surfaces, and Agricultural Land, accounted for 81% to 94% of the observed loss. The maximum loss of 94% was found both in the North and the South, although the specific drivers differed. In the North, the urban district of Kassel, located near a former orchard hotspot (Figure 2a), showed the highest proportional conversion to Residential Buildings (Table 4, Figure 6). In contrast, in the South, the districts Bergstraße and Odenwald, which were also former (and are recent) hotspots of traditional orchards (Figure 2a,b), were predominantly characterised by conversion to Agricultural Land (Table 4, Figure 6).

Regarding the third main driver, major conversions to Artificial Surfaces were observed in the urban districts of Frankfurt and Offenbach near the Main River (Table 4, Figure 6), areas that coincide with the third historical hotspot and that have experienced high orchard losses (Figure 2a,b). The conversion to Other Vegetation and Water Bodies was highest in the district of Groß-Gerau in the South, although the area and proportion were low (Table 4). The Centre contained districts with the highest, but proportionally still minor, conversions to Forests and Woody Features in Lahn–Dill and Limburg–Weilburg (Table 4, Figure 6).

In summary, the three historical traditional orchard hotspots (Figure 2) were also areas of major conversions, driven by different factors in each region (Table 4, Figure 6). Accordingly, the three main drivers showed moderate Spearman rank correlations of −0.42 for Agriculture, 0.37 for Artificial Surfaces, and 0.32 for Residential Buildings along a South–North gradient at the state level, while all other drivers were only weakly correlated (Table 4).

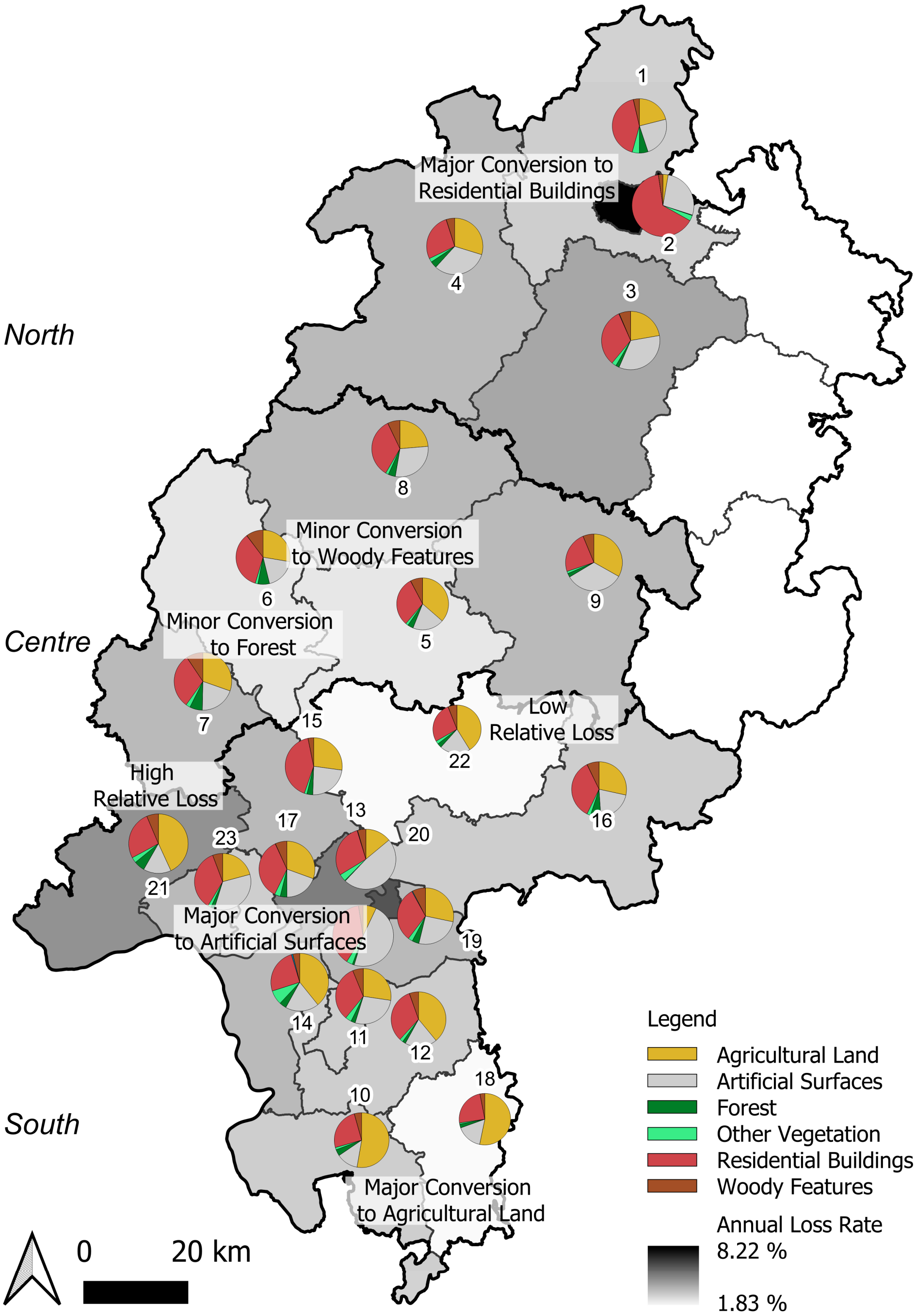


Figure 6. Map of traditional orchard conversion into other Land Use/Land Cover (LULC) types including loss rate per district. The numbers of the districts correspond to the numbers in Table 4.

4. Discussion

Traditional orchards are complex landscape elements. This complexity is reflected by their different characteristics and different spatio-temporal dynamics at the local and regional scales. In this study, we analysed, to the best of our knowledge, the most comprehensive data set for temperate European orchards. Our findings revealed several key insights:

(a) A decline in traditional orchards: The number and area of traditional orchards have significantly decreased across Hesse, with the pattern of decline varying by region. Notably, major losses occurred near historical hotspots.

(b) Characteristics of old vs. new orchards: Historically old orchards tended to have larger Areas, higher Shape Complexity, and were located closer to settlements, highways, and neighbouring orchards. In contrast, newly established orchards were often found at higher elevations and on steeper slopes.
(c) Regional differences: Despite significant differences in orchard attributes, the regions could only be distinguished in a two-class model, with the Centre being merged with the North. This highlights the distinctiveness of the traditional orchards in the South.
(d) Hotspots of orchard loss: The three historical orchard hotspots also experienced the most notable losses, driven by different factors in each region. In two hotspots, the expansion of Artificial Surfaces and Residential Buildings was the primary driver, while in the southernmost hotspot, conversion to Agricultural Land played a dominant role.

Generalising findings about temporal dynamics and the loss of traditional orchards is a challenging task and requires fine-scale spatial data to broad spatial extents. The median annual loss rate of 3.37% in Hesse is notably high and aligned with and exceeded maximum loss rates reported by case studies in Austria (3.47% [79]) and France (2.80% [80]), as reported by Plieninger et al. [23]. Even in districts with the lowest loss rates and the lowest proportional loss, such as the Wetterau, the losses exceeded those observed in similar studies. For example, the lowest loss rates and highest ratio of recent and historical orchard areas, of 1.83% and 41%, respectively, were more than double those observed in a study in southwest Germany for a similar time span and a slightly smaller area [23]. Therefore, overall orchard loss in Hesse is notably high even in areas where small gains due to newly established orchards were observed and new hotspots have emerged. Additionally, the strong differences within Hesse compared to southwestern Germany [23] that were found in this study underline the necessity of comprehensive historical data to evaluate the severeness and spatial patterns of traditional orchard loss.

Distance to settlements and main roads were identified as the main drivers of orchard decline in southwestern Germany [23]. In our study, the expansion of Artificial Surfaces and Residential Buildings emerged as the most critical factor contributing to orchard decline in two historic orchard hotspots, which aligns with the model regions for Hesse proposed by Henle et al. [3]. In addition, lost orchards were typically located closer to highways, with both proximity to highways and settlements being important factors that distinguished orchards in the South from those in the Centre and North. In contrast, in the third hotspot located in the South (Bergstraße), orchard decline was primarily driven by conversion to Agricultural Land. In general, the high proportion of conversion to Agricultural Land in Hesse is likely a result of agricultural policy changes in Germany during the 1950s (e.g., Emser Beschluss in 1953) that encouraged and financially supported the conversion of traditional agroforestry systems into grasslands or arable land. Additionally, the European Community's grubbing-up scheme, which continued until 1974, further accelerated this trend [81]. Conversion to Agricultural Land also showed the strongest correlation along the south–north gradient, indicating its significant impact, particularly in the South, where, traditionally, horticulture and special crops played an important role in agricultural production due to the favourable growing conditions, but also to socioeconomic reasons and local agricultural structures [82]. Changes in the latter two were also the main reasons for the decline of orchards, e.g., in the form of conversion to other agricultural uses [82]. Furthermore, orchard decline might also result from abandonment, leading to succession towards dense woody vegetation and forests [7], a trend observed in the Centre region. This trend could have been overlooked if the focus had been solely on model regions and/or historic orchard hotspots. Overall, the drivers of orchard loss and the characteristics of orchards themselves are manifold and vary both regionally and locally. Despite this heterogeneity, the Random Forest-based classification model for the two classes reached good and fairly balanced accuracies for a real-world ecological data set (see, e.g., [83]) underlining the distinctive features of the South compared the rest of the state. However, the feature importance changed between historic and recent data sets, indicating that even though orchards can be discriminated with similar accuracies, the temporal dimension needs to be considered to understand why they can be distinguished. While Random Forest is one of the most popular algorithms used in landscape ecological studies, novel methods based on Deep Learning are on the horizon, which would enable a deeper analysis of complex data [84]. Such approaches might be able to decipher even local differences across landscapes, but appropriate geospatial data on orchard distribution, orchard attributes, and drivers of loss are required to train and validate such novel algorithms. Therefore, this study highlights the need for data at broad spatial extents to fully understand the dynamics of these small, but important landscape elements.

High-resolution spatial data of traditional orchards, acquired in a standardised way, are essential. Not only could they address data gaps in model regions [3] or correct existing cadastral data products [3,85], these data are crucial for effective conservation planning [4], monitoring compliance with agricultural policies, and guiding landscape planning in the context of compensation measures [12], especially in orchard hotspots such as southern Hesse, where an expansion of Artificial Surfaces and Residential Buildings is to be expected [86]. Moreover, spatial maps of traditional orchards can also be used for computing carbon sequestration potentials [11,16] and other ecosystem services [11], and are also central to biodiversity studies on orchards at the landscape scale [4]. For instance, the area requirements of species within orchards and the importance of habitat connectivity are still poorly understood and it remains an open question whether species that require larger areas can also thrive in landscapes characterised by smaller, but well-connected orchards [4]. A local study in one of the orchard hotspots in southern Hesse by [87] demonstrated that the diversity and number of protected bird species increase with the size and connectivity of orchards, emphasising the conservation priority for such landscape features. Similarly, a study by [88], which compared 30 traditional orchards, found that the effects of habitat isolation can be more important than habitat amount in traditional orchards, with these effects likely being specific to different species groups. Furthermore, the links between orchard size, isolation, and species traits are still underexplored [4]. Given these challenges, multitemporal spatial data sets on traditional orchards, which can also provide insights into orchard age and historical fragmentation, are essential for a wide range of applications, from basic ecological research to the computation of ecosystem services and environmental planning.

While using manual image interpretation to produce maps of traditional orchards is highly accurate, it is also labour-intensive and costly, highlighting the need for automatised approaches. In this context, novel methods from the field of Artificial Intelligence (AI) could play a transformative role. Deep Learning approaches have already been successfully applied to vegetation mapping [89–91], including the classification of historical imagery [92] and the identification of individual tree canopies [93]. AI models that leverage information from existing, general databases (e.g., [91]), as well as specific reference data on orchards (e.g., [3]) and similar landscape elements such as small woody features [85] from public sources, could enable high-resolution orchard mapping across broad spatial extents. Additionally, these models could enhance the transferability of mapping techniques between regions or states, as traditional orchards are not only diverse landscape features by themselves, but also occur within landscapes of varying complexity [16].

Beyond quantitative parameters, there is also a notable lack of data on orchard quality [3]. This includes spatial information on the number and area of individual trees [3], shrub encroachment, and succession towards forests [3,7,24]. Recent advances in deriving parameters on ecosystem structure from 3D remote sensing data [94] could facilitate the mapping of quality indicators for traditional orchards. For example, the increasing availability of airborne laser scanning (LiDAR) data allows for multitemporal analyses of tree dimensions, ground vegetation growth, and developments towards forest-type vegetation [32]. Therefore, in line with the recently published strategic dialogue on the future of EU agriculture [20], we advocate for the adoption of novel technologies to support the analysis of dynamics of complex landscape features and traditional agroforestry systems such as traditional orchards, promoting landscape monitoring and management in the context of agricultural policies, compensation measures, and nature conservation.

5. Conclusions

Traditional agroforestry systems in Central Europe, such as orchard meadows, are in decline, and the state of Hesse is no exception. Local annual loss rates are high, and major losses occur near hotspots, but both patterns and drivers vary locally and regionally. Orchards in the traditional hotspot region in the South are characterised by distinctive topographical, ecological, and socioeconomic attributes compared to the rest of the state, but the importance of these attributes changes over time. Newly established orchards are often situated at higher elevations and on steeper slopes, while historically old orchards were located closer to settlements, highways, and neighbouring orchards, and were characterised by comparably larger areas and higher complexity. The most important drivers of loss were expansions of Artificial Areas, Residential Buildings, and Agricultural Land, while, locally, conversions into Forests or Woody Features also occurred. Comparisons to other study areas are helpful but limited due to the unavailability of spatial data. Therefore, we emphasise the necessity of high-resolution, multitemporal maps of these complex and biodiverse landscape features to enable evaluation of the severity of orchard loss and to facilitate the monitoring of the condition of traditional orchards in terms of quantity and quality. Continuous and long-term geospatial data on traditional orchards could also provide information on orchard age and the dynamics of orchard fragmentation, serving as backbone data for basic ecological research, calculations of ecosystem services, and environmental planning. Recent advances in geospatial technology and analysis have the promising but untapped potential to simplify the retrieval of orchard maps including quality indicators over broad spatio-temporal extents in support of agroecological schemes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13101639/s1, Table S1. Recoding of the Basis-DLM classes Table S2. Descriptive statistics of traditional orchards in total and for each region based on the historic (1952–1967) data set. Table S3. Descriptive statistics of traditional orchards in total and for each region based on the recent (2008–2010) data set. Table S4. Descriptive statistics of traditional orchards in total and for each region for newly established (Gain) traditional orchards between 1952–1967 and 2008–2010. Table S5. Descriptive statistics of traditional orchards in total and for each region for lost (Loss) traditional orchards between 1952–1967 and 2008–2010. Table S6. Descriptive statistics of traditional orchards in total and for each region for traditional orchards that remained (Remain) between 1952–1967 and 2010. Table S7. Confusion matrix of the two-class Random Forest classification model for the historic test set data. Table S8. Confusion matrix of the two-class Random Forest classification model for the recent test set data. Table S9. Accuracy metrics of the three-class Random Forest classification model for the historic test set data. Table S10. Accuracy metrics of the three-class Random Forest classification model for the recent test set data. Table S11. Confusion matrix of the three-class Random Forest classification model for the historic test set data. Table S12. Confusion matrix of the three-class Random Forest classification model for the recent test set data. Figure S1. Variable importance of the three-class Random Forest classification model for both the (**a**) historic and the (**b**) recent data. Video S1. Animation of traditional orchard density in Hesse for historical (1952–1967), recent (2008–2010), gained, lost and remaining orchards. Data S1. Vector data set of traditional orchards in Hesse in *gpkg-format and coordinate reference system EPSG 25832 to be opened in a Geographic Information System.

Author Contributions: Conceptualization, A.G.-S. and T.K.; methodology, A.G.-S.; formal analysis, A.G.-S. and M.S.; investigation, A.G.-S.; data curation, A.G.-S.; writing—original draft preparation, A.G.-S.; writing—review and editing, A.G.-S., A.H., M.S. and T.K.; visualisation, A.G.-S., A.H. and M.S.; supervision, A.G.-S. and T.K.; project administration, T.K.; funding acquisition, A.G.-S. and T.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: New raw data created in the study are included in the Supplementary Materials; further inquiries can be directed to the corresponding author.

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References

1. Herzog, F. Streuobst: A Traditional Agroforestry System as a Model for Agroforestry Development in Temperate Europe. *Agrofor. Syst.* **1998**, *42*, 61–80. [CrossRef]
2. Forejt, M.; Syrbe, R.-U. The Current Status of Orchard Meadows in Central Europe: Multi-Source Area Estimation in Saxony (Germany) and the Czech Republic. *Morav. Geogr. Rep.* **2019**, *27*, 217–228. [CrossRef]
3. Henle, K.; Hüttner, M.-L.; Kasperidus, H.D.; Krämer, J.; Rösler, M.; Bartelt, S.; Brümmer, A.; Clauß, B.; Clauß, J.; Délétroz, C.; et al. *Streuobstbestände in Deutschland*; Bundesamt für Naturschutz: Bonn, Germany, 2024.
4. Sattler, C.; Schrader, J.; Hüttner, M.-L.; Henle, K. Effects of Management, Habitat and Landscape Characteristics on Biodiversity of Orchard Meadows in Central Europe: A Brief Review. *Nat. Conserv.* **2024**, *55*, 103–134. [CrossRef]
5. Steffan-Dewenter, I.; Leschke, K. Effects of Habitat Management on Vegetation and Above-Ground Nesting Bees and Wasps of Orchard Meadows in Central Europe. *Biodivers. Conserv.* **2003**, *12*, 1953–1968. [CrossRef]
6. Kajtoch, Ł. The Importance of Traditional Orchards for Breeding Birds: The Preliminary Study on Central European Example. *Acta Oecologica* **2017**, *78*, 53–60. [CrossRef]
7. Kajtoch, Ł. Loss of Traditional Orchards and Its Impact on the Occurrence of Threatened Tree-Dwelling Bird Species. *Agriculture* **2023**, *13*, 2267. [CrossRef]
8. Kay, S.; Rega, C.; Moreno, G.; den Herder, M.; Palma, J.H.N.; Borek, R.; Crous-Duran, J.; Freese, D.; Giannitsopoulos, M.; Graves, A.; et al. Agroforestry Creates Carbon Sinks Whilst Enhancing the Environment in Agricultural Landscapes in Europe. *Land Use Policy* **2019**, *83*, 581–593. [CrossRef]
9. Dahlem, R.; Dehe, C.; Engler, K.; Fix, R.; Hagebölling, K.; Hein, T.; Lengert, F.; Musche, J.; Schierenbeck, L.; Simon, L.; et al. *Streuobstwiesen. Ökologische Bedeutung-Pflege-Nutzung-Förderprogramm*; Landesamt für Umweltschutz und Gewerbeaufsicht Rheinland-Pfalz (LfUG): Oppenheim, Germany, 2002.
10. Paprštein, F.; Holubec, V.; Sedlák, J. Inventory and Conservation of Fruit Tree Landraces as Cultural Heritage of Bohemian Forest (Czech Republic), Indicators for Former Settlements of Ethnic Minorities. *Genet. Resour. Crop Evol.* **2015**, *62*, 5–11. [CrossRef]
11. Kay, S.; Crous-Duran, J.; García De Jalón, S.; Graves, A.; Palma, J.H.N.; Roces-Díaz, J.V.; Szerencsits, E.; Weibel, R.; Herzog, F. Landscape-Scale Modelling of Agroforestry Ecosystems Services in Swiss Orchards: A Methodological Approach. *Landsc. Ecol.* **2018**, *33*, 1633–1644. [CrossRef]
12. Geske, C. Streuobstwiesen in Hessen—Ein Landschaftselement mit agrarpolitischer und ökonomischer Geschichte. *Jahrb. Naturschutz Hess.* **2018**, *17*, 66–72.
13. Bieling, C.; Plieninger, T. Recording Manifestations of Cultural Ecosystem Services in the Landscape. *Landsc. Res.* **2013**, *38*, 649–667. [CrossRef]
14. Schüpbach, B.; Zgraggen, K.; Szerencsits, E. Incentives for Low-Input Land-Use Types and Their Influence on the Attractiveness of Landscapes. *J. Environ. Manag.* **2008**, *89*, 222–233. [CrossRef] [PubMed]
15. Ohnesorge, B.; Bieling, C.; Schleyer, C.; Plieninger, T. Cultural Landscapes and Their Ecosystem Services. The Example of Orchard Meadows in the Swabian Alb Biosphere Reserve. In *Ecosystem Services—Concept, Methods and Case Studies*; Grunewald, K., Bastian, O., Eds.; Springer: Berlin/Heidelberg, Germany, 2015; pp. 224–231.
16. Golicz, K.; Ghazaryan, G.; Niether, W.; Wartenberg, A.C.; Breuer, L.; Gattinger, A.; Jacobs, S.R.; Kleinebecker, T.; Weckenbrock, P.; Große-Stoltenberg, A. The Role of Small Woody Landscape Features and Agroforestry Systems for National Carbon Budgeting in Germany. *Land* **2021**, *10*, 1028. [CrossRef]
17. Kraft, P.; Rezaei, E.E.; Breuer, L.; Ewert, F.; Große-Stoltenberg, A.; Kleinebecker, T.; Seserman, D.-M.; Nendel, C. Modelling Agroforestry's Contributions to People—A Review of Available Models. *Agronomy* **2021**, *11*, 2106. [CrossRef]
18. Plieninger, T. Capitalizing on the Carbon Sequestration Potential of Agroforestry in Germany's Agricultural Landscapes: Realigning the Climate Change Mitigation and Landscape Conservation Agendas. *Landsc. Res.* **2011**, *36*, 435–454. [CrossRef]
19. Smith, J.; Pearce, B.D.; Wolfe, M.S. Reconciling Productivity with Protection of the Environment: Is Temperate Agroforestry the Answer? *Renew. Agric. Food Syst.* **2013**, *28*, 80–92. [CrossRef]
20. European Commission. *Strategic Dialogue on the Future of EU Agriculture. A Shared Prospect for Farming and Food in Europe*; European Commission (EC): Brussels, Belgium, 2024.

21. Finck, P.; Heinze, S.; Raths, U.; Riecken, U.; Ssymank, A. *Rote Liste der Gefährdeten Biotoptypen Deutschlands. Dritte Fortgeschriebene Fassung 2017*; Bundesamt für Naturschutz (BfN): Bonn-Bad Godesberg, Germany, 2017.
22. Lukas, A.; Schröter, J. Streuobstwiesen. Gesetzlicher Biotopschutz Nach § 30 BNatSchG. *Naturschutz Landschaftsplanung* **2022**, *54*, 38–39.
23. Plieninger, T.; Levers, C.; Mantel, M.; Costa, A.; Schaich, H.; Kuemmerle, T. Patterns and Drivers of Scattered Tree Loss in Agricultural Landscapes: Orchard Meadows in Germany (1968–2009). *PLoS ONE* **2015**, *10*, e0126178. [CrossRef]
24. Špulerová, J.; Piscová, V.; Gerhátová, K.; Bača, A.; Kalivoda, H.; Kanka, R. Orchards as Traces of Traditional Agricultural Landscape in Slovakia. *Agric. Ecosyst. Environ.* **2015**, *199*, 67–76. [CrossRef]
25. HMUKLV. *Streuobstwiesen in Hessen-Heimat des Apfelweins-Zuhause für den Steinkauz*; Hessisches Ministerium für Umwelt, Klimaschutz, Landwirtschaft und Verbraucherschutz (HMUKLV): Wiesbaden, Germany, 2022.
26. Landesregierung Hessen. *Koalitionsvertrag Zwischen CDU und SPD Für Die 21. Legislaturperiode 2024–2029*; Landesregierung Hessen: Wiesbaden, Germany, 2024.
27. HVBG ATKIS® Basis-DLM. Digitales Basis-Landschaftsmodell, Modellierung der Landschaftsbezogenen Geoinformationen. Hessische Verwaltung für Bodenmanagement und Geoinformation (HVBG). Available online: https://hvbg.hessen.de/landesvermessung/geotopographie/digitales-basis-landschaftsmodell (accessed on 6 September 2024).
28. HLNUG Methodendokumentation Bodenkunde/Bodenschutz. *Ertragspotenzial Des Bodens in Hessen (BFD50)*; Hessisches Landesamt Für Naturschutz, Umwelt und Geologie (HLNUG): Wiesbaden, Germany, 2021.
29. HLNUG Ertragspotenzial Des Bodens in Hessen (BFD50). Shapefile. Hessisches Landesamt Für Naturschutz, Umwelt und Geologie (HLNUG). Available online: https://www.geoportal.hessen.de/mapbender/php/mod_iso19139ToHtml.php?url=https://www.geoportal.hessen.de/mapbender/php/mod_dataISOMetadata.php?outputFormat=iso19139&id=5450bd65-0b1f-1c52-2945-218e31ba6aff (accessed on 4 September 2024).
30. HVBG ATKIS® DGM. Digitale Geländemodelle. Available online: https://hvbg.hessen.de/landesvermessung/geotopographie/3d-daten/digitale-gelaendemodelle (accessed on 6 September 2024).
31. *HLNUG Luftbildinterpretation Streuobst und Gehölze*; Hessisches Landesamt Für Naturschutz, Umwelt und Geologie (HLNUG): Wiesbaden, Germany, 2017.
32. Große-Stoltenberg, A.; Hanzl, A.; Schnepel, N.; Kleinebecker, T. Entwicklung eines fernerkundungsbasierten Monitoringsystems für Streuobstwiesen in Hessen mit Fokus auf 3D-Laserscanningdaten (Projekt MOST3D). *Jahrb. Natursch. Hessen* **2023**, *22*, 55–60.
33. Statistisches Bundesamt Fläche und Bevölkerung nach Ländern. Available online: https://www.statistikportal.de/de/bevoelkerung/flaeche-und-bevoelkerung (accessed on 6 September 2024).
34. Eurostat NUTS—Nomenclature of Territorial Units for Statistics. Available online: https://ec.europa.eu/eurostat/web/nuts (accessed on 6 September 2024).
35. Kallert, A.; Belina, B.; Miessner, M.; Naumann, M. The Cultural Political Economy of Rural Governance: Regional Development in Hesse (Germany). *J. Rural Stud.* **2021**, *87*, 327–337. [CrossRef]
36. HMLU Wir Machen den Wald klimastabil. Hessische Ministerium für Landwirtschaft und Umwelt, Weinbau, Forsten, Jagd und Heimat (HMLU). Available online: https://landwirtschaft.hessen.de/wald (accessed on 6 September 2024).
37. Jauker, F.; Diekötter, T.; Schwarzbach, F.; Wolters, V. Pollinator Dispersal in an Agricultural Matrix: Opposing Responses of Wild Bees and Hoverflies to Landscape Structure and Distance from Main Habitat. *Landsc. Ecol.* **2009**, *24*, 547–555. [CrossRef]
38. Reger, B.; Mattern, T.; Otte, A.; Waldhardt, R. Assessing the Spatial Distribution of Grassland Age in a Marginal European Landscape. *J. Environ. Manag.* **2009**, *90*, 2900–2909. [CrossRef]
39. Leßmann, B.; Scharpff, H.-J.; Wedel, A.; Wiegand, K. *Grundwasser im Vogelsberg*; Hessisches Ministerium für Umwelt, Landwirtschaft und Forsten, Hessisches Landesamt für Umwelt und Geologie: Wiesbaden, Germany, 2000.
40. HLNUG Beobachteter Klimawandel. *Klimawandel in Hessen*; Hessisches Landesamt Für Naturschutz, Umwelt und Geologie (HLNUG): Wiesbaden, Germany, 2018.
41. Huebener, H.; Gelhardt, U.; Lang, J. Improved Representativeness of Simulated Climate Using Natural Units and Monthly Resolution. *Front. Clim.* **2022**, *4*, 991082. [CrossRef]
42. HLNUG Klimawandel in Hessen. *Fachzentrum Klimawandel und Anpassung*; Hessisches Landesamt Für Naturschutz, Umwelt und Geologie (HLNUG): Wiesbaden, Germany, 2018.
43. Safaei, M.; Kleinebecker, T.; Große-Stoltenberg, A. Potential of the Satellite-based Dynamic Habitat Index (DHI) to capture changes in soil properties and drought conditions across Land Use/Land Cover types in a Central European landscape. *Geocarto Int.* **2022**, *38*, 2292162. [CrossRef]
44. HLNUG Neuerfassung von Gehölzen, Baumreihen, Alleen und Streuobst Mittels Visueller Interpretation von Digitalen Orthophotos für Ganz Hessen zur Aktualisierung der Ergebnisse der Hessischen Biotopkartierung. Informationen zur Erfassung der Einzelnen Objekte. Hessisches Landesamt für Naturschutz, Umwelt und Geologie (HLNUG). Available online: https://natureg.hessen.de/resources/recherche/HLNUG/Lebensraeume/Information_%20zur_%20Erfassung_der_einzelnen_Objekte_der_Luftbildinterpretation.pdf (accessed on 4 September 2024).
45. HVBG Historischen Luftbilder Aus Den Jahren 1952–1967. Geoportal Hessen. Available online: https://www.geoportal.hessen.de/map?WMC=2217 (accessed on 6 September 2024).
46. Lindsay, J. Patch Shape Tools—WhiteboxTools User Manual. Available online: https://www.whiteboxgeo.com/manual/wbt_book/available_tools/gis_analysis_patch_shape_tools.html (accessed on 4 September 2024).

47. Hijmans, R. Terra: Spatial Data Analysis. Available online: https://github.com/rspatial/terra (accessed on 6 September 2024).
48. Pebesma, E. Simple Features for R: Standardized Support for Spatial Vector Data. *R J.* **2018**, *10*, 439. [CrossRef]
49. Pebesma, E.; Bivand, R. *Spatial Data Science: With Applications in R*; Chapman and Hall/CRC: New York, NY, USA, 2023.
50. Baston, D. Exactextractr: Fast Extraction from Raster Datasets Using Polygons. Available online: https://CRAN.R-project.org/package=exactextractr (accessed on 6 September 2024).
51. Wickham, H.; François, R.; Henry, L.; Müller, K.; Vaughan, D. Dplyr: A Grammar of Data Manipulation. Available online: https://dplyr.tidyverse.org (accessed on 6 September 2024).
52. Pebesma, E.; Mailund, T.; Hiebert, J. Measurement Units in R. *R J.* **2016**, *8*, 486–494. [CrossRef]
53. Dorman, M. Nngeo: K-Nearest Neighbor Join for Spatial Data. Available online: https://github.com/michaeldorman/nngeo/ (accessed on 6 September 2024).
54. Sjoberg, D.D.; Whiting, K.; Curry, M.; Lavery, J.A.; Larmarange, J. Reproducible Summary Tables with the Gtsummary Package. *R J.* **2021**, *13*, 570–580. [CrossRef]
55. Iannone, R.; Cheng, J.; Schloerke, B.; Hughes, E.; Lauer, A.; Seo, J.; Ken, B.; Olivier, R. Gt: Easily Create Presentation-Ready Display Tables. Available online: https://github.com/rstudio/gt (accessed on 6 September 2024).
56. R Development Core Team. R: A Language and Environment for Statistical Computing. R foundation for Statistical Computing: Vienna, Austria, 2024.
57. *HVBG Digitale Verwaltungsgrenzen Hessen*; Hessische Verwaltung Für Bodeninformation und Geoinformation (HVBG): Wiesbaden, Germany, 2024.
58. Birch, C.P.D.; Oom, S.P.; Beecham, J.A. Rectangular and Hexagonal Grids Used for Observation, Experiment and Simulation in Ecology. *Ecol. Model.* **2007**, *206*, 347–359. [CrossRef]
59. Shapiro, S.S.; Wilk, M.B. An Analysis of Variance Test for Normality (Complete Samples). *Biometrika* **1965**, *52*, 591–611. [CrossRef]
60. Bartlett, M.S. Properties of Sufficiency and Statistical Tests. *Proc. R. Soc. Lond. Ser.-Math. Phys. Sci.* **1937**, *160*, 268–282. [CrossRef]
61. Kruskal, W.H.; Wallis, W.A. Use of Ranks in One-Criterion Variance Analysis. *J. Am. Stat. Assoc.* **1952**, *47*, 583–621. [CrossRef]
62. Benjamini, Y.; Hochberg, Y. Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *J. R. Stat. Soc. Ser. B Methodol.* **1995**, *57*, 289–300. [CrossRef]
63. Breiman, L. Random Forests. *Mach. Learn.* **2001**, *45*, 5–32. [CrossRef]
64. Fernández-Delgado, M.; Cernadas, E.; Barro, S.; Amorim, D. Do We Need Hundreds of Classifiers to Solve Real World Classification Problems? *J. Mach. Learn. Res.* **2014**, *15*, 3133–3181. [CrossRef]
65. Große-Stoltenberg, A.; Hellmann, C.; Werner, C.; Oldeland, J.; Thiele, J. Evaluation of Continuous VNIR-SWIR Spectra versus Narrowband Hyperspectral Indices to Discriminate the Invasive Acacia Longifolia within a Mediterranean Dune Ecosystem. *Remote Sens.* **2016**, *8*, 334. [CrossRef]
66. Kuhn, M. The Caret Package. Available online: https://topepo.github.io/caret/index.html (accessed on 6 September 2024).
67. Puyravaud, J.-P. Standardizing the Calculation of the Annual Rate of Deforestation. *For. Ecol. Manag.* **2003**, *177*, 593–596. [CrossRef]
68. Zar, J.H. Spearman Rank Correlation: Overview. In *Wiley StatsRef: Statistics Reference Online*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2014; ISBN 978-1-118-44511-2.
69. Fox, J.; Weisberg, S. *An R Companion to Applied Regression*, 3rd ed.; Sage: Thousand Oaks, CA, USA, 2019.
70. Graves, S.; Piepho, H.; Selzer, L. multcompView: Visualizations of Paired Comparisons. R foundation for Statistical Computing: Vienna, Austria, 2024.
71. Wickham, H. *Ggplot2: Elegant Graphics for Data Analysis.*; Springer: New York, NY, USA, 2016.
72. Auguie, B. gridExtra: Miscellaneous Functions for "Grid" Graphics. Available online: https://CRAN.R-project.org/package=gridExtra (accessed on 6 September 2024).
73. Xu, S.; Chen, M.; Feng, T.; Zhan, L.; Zhou, L.; Yu, G. Use Ggbreak to Effectively Utilize Plotting Space to Deal with Large Datasets and Outliers. *Front. Genet.* **2021**, *12*, 774846. [CrossRef]
74. Wilke, C.O. Cowplot: Streamlined Plot Theme and Plot Annotations for "ggplot2". Available online: https://cran.r-project.org/package=cowplot (accessed on 6 September 2024).
75. Liaw, A.; Wiener, M. Classification and Regression by randomForest. *R News* **2002**, *2*, 18–22.
76. Folashade, D. doParallel: Foreach Parallel Adaptor for the "Parallel" Package. Available online: https://CRAN.R-project.org/package=doParallel (accessed on 6 September 2024).
77. Wei, T.; Simko, V. Corrplot: Visualization of a Correlation Matrix. Available online: https://cran.r-project.org/web/packages/corrplot/index.html (accessed on 6 September 2024).
78. QGIS.org QGIS Geographic Information System. Open Source Geospatial Foundation Project. Version 3.34 "Prizren" LTR. Available online: https://www.qgis.org (accessed on 1 December 2023).
79. Bernkopf, S. Geschichte Des Österreichischen Obstbaues. In *Alte Obstsorten und Streuobstbau in Österreich*; Bundesministerium für Umwelt: Wien, Germany, 1994; pp. 41–102.
80. Pointereau, P.; Coulon, F. *Reflecting Environmental Land Use Needs into EU Policy: Preserving and Enhancing the Environmental Benefits of Unfarmed Features on EU Farmland. Case Study Report, France. Study for DG ENV Ref ENV.B.1/ETU/2007/0033*; Institute for European Environmental Policy UK (IEEP UK): London, UK, 2008.

81. Güll, R. Streuobstwiesen. Von der früheren Normalität bis zur heutigen Einzigartigkeit. *Stat. Monatsheft Baden-Württ.* **2015**, *12*, 38–42.
82. Pletsch, A. *Bundesrepublik Deutschland und Berlin West, Hessen*; Wissenschaftliche Buchgesellschaft: Darmstadt, Germany, 1989.
83. Cutler, D.R.; Edwards Jr, T.C.; Beard, K.H.; Cutler, A.; Hess, K.T.; Gibson, J.; Lawler, J.J. Random Forests for Classification in Ecology. *Ecology* **2007**, *88*, 2783–2792. [CrossRef] [PubMed]
84. Stupariu, M.S.; Cushman, S.A.; Pleşoianu, A.I.; Pătru-Stupariu, I.; Fuerst, C. Machine learning in landscape ecological analysis: A review of recent approaches. *Landsc. Ecol.* **2022**, *37*, 1227–1250. [CrossRef]
85. Patriarca, A.; Caputi, E.; Gatti, L.; Marcheggiani, E.; Recanatesi, F.; Rossi, C.M.; Ripa, M.N. Wide-Scale Identification of Small Woody Features of Landscape from Remote Sensing. *Land* **2024**, *13*, 1128. [CrossRef]
86. Dembski, S.; Sykes, O.; Couch, C.; Desjardins, X.; Evers, D.; Osterhage, F.; Siedentop, S.; Zimmermann, K. Reurbanisation and Suburbia in Northwest Europe: A Comparative Perspective on Spatial Trends and Policy Approaches. *Prog. Plan.* **2021**, *150*, 100462. [CrossRef]
87. Bauschmann, G. Untersuchungen über die Vogelwelt dreier unterschiedlich strukturierter Streuobstgebiete im mittleren Hessen. *Beitr. Zur Naturkunde Wetterau* **2005**, *11*, 137–150.
88. Bailey, D.; Schmidt-Entling, M.H.; Eberhart, P.; Herrmann, J.D.; Hofer, G.; Kormann, U.; Herzog, F. Effects of Habitat Amount and Isolation on Biodiversity in Fragmented Traditional Orchards. *J. Appl. Ecol.* **2010**, *47*, 1003–1013. [CrossRef]
89. Ma, L.; Liu, Y.; Zhang, X.; Ye, Y.; Yin, G.; Johnson, B.A. Deep Learning in Remote Sensing Applications: A Meta-Analysis and Review. *ISPRS J. Photogramm. Remote Sens.* **2019**, *152*, 166–177. [CrossRef]
90. Hoeser, T.; Bachofer, F.; Kuenzer, C. Object Detection and Image Segmentation with Deep Learning on Earth Observation Data: A Review—Part II: Applications. *Remote Sens.* **2020**, *12*, 3053. [CrossRef]
91. Kattenborn, T.; Leitloff, J.; Schiefer, F.; Hinz, S. Review on Convolutional Neural Networks (CNN) in Vegetation Remote Sensing. *ISPRS J. Photogramm. Remote Sens.* **2021**, *173*, 24–49. [CrossRef]
92. Mboga, N.; Grippa, T.; Georganos, S.; Vanhuysse, S.; Smets, B.; Dewitte, O.; Wolff, E.; Lennert, M. Fully Convolutional Networks for Land Cover Classification from Historical Panchromatic Aerial Photographs. *ISPRS J. Photogramm. Remote Sens.* **2020**, *167*, 385–395. [CrossRef]
93. Weinstein, B.G.; Marconi, S.; Bohlman, S.; Zare, A.; White, E. Individual Tree-Crown Detection in RGB Imagery Using Semi-Supervised Deep Learning Neural Networks. *Remote Sens.* **2019**, *11*, 1309. [CrossRef]
94. Valbuena, R.; O'Connor, B.; Zellweger, F.; Simonson, W.; Vihervaara, P.; Maltamo, M.; Silva, C.A.; Almeida, D.R.A.; Danks, F.; Morsdorf, F.; et al. Standardizing Ecosystem Morphological Traits from 3D Information Sources. *Trends Ecol. Evol.* **2020**, *35*, 656–667. [CrossRef]