University of Zurich[UZH]

Characterisation of the Evolution of Vineyards in Canton of Ticino and Moesa Region since the 1930s

GEO 511 Master's Thesis

Author
Lisa Wyler
15-727-027

Supervised by
Patrik Krebs (patrik.krebs@wsl.ch)
Prof. Dr. Ross Purves

Faculty representative
Prof. Dr. Ross Purves

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Department of Geography, University of Zurich

Contents

Abstract

The evolution of vineyard areas in the Canton of Ticino and in the Moesa Region has been characterised. Vineyard areas from three different time windows (1934, 1989 and 2018) were compared and analysed taking into account geomorphological, land cover and socio-economic factors. Only one type of driving factor category is not enough to explain how the evolution of vineyard areas was influenced. Vineyard area decreased since the 1930s, but with different patterns over the study area and over the century. Descriptive methods are important to get an overview of temporal and spatial differences in the evolution. Nevertheless, a simple statistical tool is essential to obtain quantitative results in addition to the qualitative results of the descriptive analysis. For future studies, it is important to further investigate the driving factors using modelling techniques. Furthermore, other possible attributes can be collected and analysed. This Master's thesis provides an insight into the evolution of vineyard area and its driving factors and thus creates a basis for future studies in this field.

1 Introduction

Many actors are involved in the production of a glass of wine drunk at home or with friends in a restaurant. Not only the individual winegrowers are needed to grow and harvest the grapes, but also the workers in the wineries and in the restaurant service as well as the final consumers are involved. This image is a strong simplification of the whole production chain, but gives the idea that many different actors can have a relationship with the vine plant.
This image is also valid for the Canton of Ticino and the Moesa Region, where the first written mentions of viticulture are from around the year 1500 AD (Panzera, 2017; Castagnola et al., 2015, a Marca et al., 2006). Vines have been cultivated in this area for centuries. Vineyards are nowadays distributed in the main valleys of the Canton of Ticino and the Moesa Region close to population centres and are therefore an attractive landscape element, especially because of their pattern given by the rows of vines. Although, the vineyards cover only 0.3% of the whole study area (Swiss Wine, 2020), the number of people involved in the wine-market is much larger than the 2855 winegrowers (SA, 2019). Particularly, during the harvest time, the number increases, as family members and friends often help the individual professional and hobby winegrowers.
In recent decades, however, there is a continuous decrease of vineyards surface (Krebs & Bertogliati, 2017).

The decrease in vineyard area also has an impact on the landscape, changing its appearance and its management. Vineyard stakeholders agree on the idea that the vineyards have a cultural value for the landscape (Maddalena, 2020b; Martinelli, 2019). Therefore, there is the need to develop a medium- to long-term strategy to preserve the tradition of vineyards and promote a sustainable-productive viticulture (IVVT, 2020a; Martinelli, 2019). It is important in this respect to characterise the evolution and changes of the vineyard area in the last century, in order to understand the current situation.
The aim of this Master’s thesis is to assess and characterise the evolution of the vineyard area over the last century, in order to understand the potential relationship between social transformation and the land cover changes.

1.1 Viticulture and landscape

"Considering the price and quantity of the wine that the Canton of Ticino can obtain from southern Italy, it will seem strange to many that the viticulture is to be maintained at all cost and that, in order to maintain it, a survey is being carried out to find ways of promoting it. Nevertheless, to abandon the vine would be an economic error of the greatest magnitude […]" (Panzera, 2017, p. 32; own translation).

This quote originates from a study on the status of viticulture in the Canton of Ticino carried out in 1893 by the professor Domenico Tamaro of the Agricultural Technical Institute in Brescia, Italy (Panzera, 2017). After 120 years, there are still studies interested in analysing the viticulture in the Canton of Ticino and Moesa Region. This Master's thesis is one of those. As the wine-growing area and the number of winegrowers in this region are continuously decreasing, there is an interest in preserving this cultivation as a traditional heritage and a very important landscape element.

Many different definitions of the Landscape concept exist. The difficulty in finding a unique definition of landscape is due to the fact that the word *landscape* can be traced back to the 10th century (BAFU, 2008). Since then the word *landscape* has been adopted for describing different concepts following cultural differences and related land uses (BAFU, 2008). The Swiss Federal Office of the Environment has its own definition, which can be considered a detailed version of the definition stated in the European Landscape Convention.

"Landscapes form spatially the lived and experienced environment of humans, which enables them as individuals and society to fulfil their physical and psychological needs. Landscapes have a variety of functions as a resource. They are habitats for people, animals and plants, diverse recreational and identification spaces, and spatial expressions of cultural heritage. They also contribute to the creation of value. Landscapes are dynamic structures and developed due to natural factors such as rocks, soil, water, air, light, fauna and flora in interaction with human use and design." (BAFU, 2008; own translation).

This definition summarises the objective and subjective dimensions of the current concept of landscape. The objective dimension consists of the natural geographical space, while the subjective dimension is represented by the subjective individual image of it (Weiss, 2013).

The definitions of the BAFU (2008) and the one of the European Landscape Convention (2000) suggest a two-dimensionality of landscape (Weiss, 2013), which is perhaps why there is no single definition. Another reason could be the fact that landscape is composed of many different elements, partially defined by the human beings and their activities. These activities are determined by human-environment and human-landscape relationships, which are structured by culture and tradition and influence the structure of the landscape (Rodríguez, Mora Delgado & Briñez, 2016).

Vineyards fully respect the bi-dimensional landscape definition. They are an easy recognisable physical element with a pronounced cultural dimension (Pozachenyuk & Yakovenko, 2018). Especially in the Canton of Ticino and the Moesa Region, vineyards are close to areas of socio-economic activities (Krebs & Bertogliati, 2017) and represent therefore important ecological, cultural, and economic elements, which provide various ecosystem services (MAE, 2005; Martinelli, 2019; Trivellone & Moretti, 2017). The exploration of the vineyard landscape is thus motivated by the need to preserve this multi-purpose landscape element (Pozachenyuk & Yakovenko, 2018).

1.2 Viticulture in Canton of Ticino and Moesa Region

Viticulture in the Canton of Ticino and Moesa Region has been in crisis for several years and is still looking for long-term solutions. The most frequently mentioned causes to explain the current difficulties in the viticulture can be divided into two categories (Tab. 1). The first includes the difficulties and the workload in vineyard management and the second the market related sale problems.

In general, the factors listed in the first category tend to cause decrease in vineyard area and the number of winegrowers leading to the abandonment of vineyards. This phenomenon has especially impact on the landscape by changing its aesthetics and decreasing its quality (Maddalena, 2020a; Di Lorenzo, 2020; Martinelli, 2019). Especially considering that vineyards are spread throughout the main valleys, they are often visible in daily life. Moreover, the decline of vineyards would affect the landscape in many ways due to their particular pattern and different characteristics depending on their location (Fig. 1 & Fig. 2).

Due to this crisis, there is a growing demand for policy and governance to develop medium-long term strategies and create tools to help individual winegrowers (Ferretti, 2020; Jelmini, 2020; Piezzi, 2020; Piezzi, 2019).

Table 1 – Summary of some causes mentioned to explain the wine-market crisis.

First category: vineyard management	Second category: selling-problems
• labour difficulties of the vineyards (Martinelli, 2019); • climate change (Martinelli, 2019); • more aggressive grape diseases (Martinelli, 2019).	• closure of the catering services between 14 March and 11 May 2020 (Di Lorenzo, 2020; Martinelli, 2019); • suspension or abolition of events (Di Lorenzo, 2020; Martinelli, 2019); • decrease in consumption (Di Lorenzo, 2020; Martinelli, 2019); • interruption of exports (Di Lorenzo, 2020; Martinelli, 2019); • undeveloped online market (Di Lorenzo, 2020; Martinelli, 2019); • foreign competition (Di Lorenzo, 2020; Martinelli, 2019)

The second reason refers to the wine-market. It should be noted that one problem is the drop in consumption, often motivated by the high prices of local wines, but perhaps the problem mentioned by Donini in 1925 is also recurring:

"The Canton of Ticino should not forget that if the Ticino's agricultural products are good enough for our Confederates, they should also be good enough for the inhabitants of the Ticino" (Panzera, 2017, p. 36; own translation).

For years, the wine production has exceeded sales, so stocks in the wineries are increasing (Maddalena, 2020a; IVVT, 2020b; Maddalena, 2020b; Martinelli, 2019). This problem worsened during the first COVID-19 pandemic lockdown in spring 2020 (Maddalena, 2020a; IVVT, 2020b; Maddalena 2020b).

Figure 1 – Hillside vineyards (from top) in Brontallo (Swiss Wine, 2016), in Boschetto (Ticino Weekend, 2014) and in Camorino (Ticino, 2020).

Figure 2 – Lowlands vineyards (from top) in Lugano (CCAT, 2020) and in Ascona (Ticino, 2021).

1.3 State of the art

1.3.1 Land use and cover change analysis

There is a great variety of researches on land use and cover changes (LUCC) and this variety is growing. These studies are important as their results can help to understand change processes with the factors and actors involved and help to develop and to foresee landscape sustainability (Camacho Olmedo et al., 2018; Liu et al., 2018). In particular, since awareness of the negative impact of human activities on the landscape and the earth system in general is becoming stronger (Camacho Olmedo et al., 2018). Negative impacts result from land alterations by the main driver, the human being (Liu et al., 2018).

Land alterations often result with the disappearance or the decrease of the quantity and quality of a particular land use and cover class. On the other hand, LUCC studies are also analysing the expansion of particular land use and cover classes. Since the human being is often the main actor, in developing areas expansion results as urban areas advance, while forests and agricultural land often decrease in size. Although, this pattern is not always applicable.

The development and use of technologies such as geographic information systems and remote sensing allow spatio-temporal changes to be assessed at different observations levels and at different resolutions (Liu et al., 2018). Remote sensing satellite imagery is enabling the analysis of various LUCC phenomena, but it is not possible to look at the changes happened at the beginning of this century.

In addition, the development of large computing capacities is enabling the modelling and the statistical analysis of LUCC (Camacho Olmedo et al., 2018). In this regard, machine learning techniques such as Random Forests (RF) are becoming important in this type of researches as among others (Zhai et al., 2020). RF is a method that can evaluate regressions, classifications and the relative importance of input variables (Liu et al., 2018; Breiman, 2001). Within LUCC studies, RF is mostly applied to evaluate land cover classifications and object-based image analysis (Zhai et al., 2020; Liu et al., 2018). In addition, RF has the potential to evaluate the importance of variables as drivers of LUCC (Zhai et al., 2020). In particular, RF has various advantages over other techniques, because it offers the possibility to make descriptions without strong model assumptions, address complex nonlinear problems and deal with different types of response variables (Zhai et al., 2020). Since RF can be used as a classification method as well as regression techniques, it can be applied to meet two objectives (Boulesteix et al., 2012). Firstly as a selector of variables by constructing a prediction rule;

secondly as a classifier of variables based on their ability to predict and influence the response variable (Boulesteix et al., 2012).

1.3.2 Historical evolution of viticulture in Canton of Ticino and Moesa Region

Viticulture in Canton Ticino and the Moesa Region has been present in the area since ancient times (Ferrari et al., 2006). The several written descriptions of it are from the end of the Middle Age and the beginning of the modern era (Panzera, 2017). Until the year 1800, there are various written accounts that make statements about viticulture, but they are mostly subjective and difficult to compare with each other. Although they have in common the description of the vineyards as distributed in most of the valleys (Panzera, 2017).

From the 19th century onwards, written records report more detail information on the management approach and the cultivated grape varieties, as well as the first agricultural statistics. In general, the distribution of vineyards is wide and goes from the plains to the mountains, but the main purpose is not the trade of the final product (Panzera, 2017). According to historical studies, mid of the 19th century represents the period with the largest vineyard area (3% of the entire regional area) and as a consequence it can be retained the reference milestone (i.e. the starting point of the decreasing trend) of vine cultivation in this region (Krebs & Bertogliati, 2017; Panzera, 2017).

In the second half of the 19th century, the wine-growing area started to decrease mainly due to two aspects (Krebs & Bertogliati, 2017; Panzera, 2017). The first is the appearance of two American grape diseases: powdery mildew (Uncinula necator) and downy mildew (Plasmopara viticola). The second aspect causing the decrease in vineyard area is the opening of the Gotthard railway line, as it requires space and land and because it facilitates the import of cheaper foreign wines (Krebs & Bertogliati, 2017; Panzera, 2017). Although, the some unorganised reconstructions of vineyards and the introduction of American vines by the state, which are more resistant to diseases and less needy, were signs that vineyards were not abandoned. However, social transformation started with the decrease of the number of workers in the agricultural sector due to emigration (Panzera, 2017) and new job opportunities (Krebs & Bertogliati, 2017). There were also weaknesses in the whole viticulture sector due to fragmentation of land ownership and mixed cultivation, and vineyards were not the main productive activity of farming families (Panzera, 2017). At the end of the 19th century, it appears a third disease, the pest grape phylloxera due to an insect (Daktulosphaira vitifoliae) (Krebs & Bertogliati, 2017; Panzera, 2017). The diseases and the construction of the railway line only showed the general weakness of the entire viticultural system in the region: lack of improvements (Krebs & Bertogliati, 2017). Moreover, vineyards were not always in the most suitable regions because they were seen as ancillary businesses and therefore individuals planted it somewhere on their land (Panzera, 2017).

With the beginning of the 20th century, the role of the state and the cantons in the viticulture increased and their aim was to improve the general cultivation and product quality and to deepen knowledge with research (Panzera, 2017). In the beginning, this duty was difficult, as many individual winegrowers had to be convinced to adopt the new measures, such as the introduction of French grape varieties, seen as more suitable. The research was and still is conducted by the school for green professions in Mezzana founded in 1912 and the agricultural research centre Agroscope in Lausanne, to which the Canton of Ticino was assigned in 1920 (Panzera, 2017). Another attempt to improve the status of viticulture was to reorganise the distribution of the parcels.

From 1950, modern viticulture began with the establishment of the Merlot grape as the most suitable in the context of the region and diseases. Furthermore, in 1948 the winegrowers organised themselves with the foundation of Federviti, the federation of winegrowers in the Swiss-Italian region (Panzera, 2017). Although the whole evolution of this century is characterised by a decrease in the vineyard area and number of winegrowers, especially since in 1957 the Confederation and the Canton stopped the reconstruction project, which had a modest result. Another characteristic is the lack of large vineyards and the presence until 1980 of two viticulture systems: the extensive one mixing different varieties and the intensive one promoting fine vines (Panzera, 2017). Socio-economic transformation to a society based on the tertiary sector, the advancement of urban areas and forest and the abandonment of difficult terrain are cited and hypothesised as reasons for the decrease (Krebs & Bertogliati, 2017; Panzera, 2017). At around 1990, first phase of the renewal process of viticulture in the Canton of Ticino and in the Moesa Region ends, characterised by the abandonment of traditional and American vines in favour of Merlot and fine grapes (Panzera, 2017).

From then on, there has been the second phase of renewal characterized by the improvement of winemaking techniques and the quality of grapes and wines (Panzera, 2017). Although the average area of vineyards has increased, the landscape of the region is still characterised by small vineyards. The Canton of Ticino released laws and plans for conservation of the agricultural land and regulate the viticulture with spatial planning methods and the decrease of vineyard area is less strong (Krebs & Bertogliati, 2017). Although, vineyards are still at risk of disappearing as many of them are located in building zones causing conflicts of use (Krebs & Bertogliati, 2017).

1.4 Research objectives

The aim of preserving the vine landscape by understanding the processes of its evolution is also the motivation for this Master’s thesis.

The main research question investigated is: how has the evolution of vineyards in the Canton of Ticino and the Moesa Region been since the 1930s?

To answer this question, the objectives of the Master's thesis are:

1. To characterise the evolution of vineyards;
2. To characterise the composition of vineyards;
3. To identify the relevant driving factors influencing the evolution of vineyards;
4. To characterise the impact of these factors on the vineyard evolution.

To this purpose, I will analyse the evolution of the vineyard area in the Canton of Ticino and the Moesa Region since the 1930s.

2 Materials and methods

The definition of the research framework is indispensable for answering the research questions by obtaining comparable and meaningful results. This chapter describes the spatio-temporal resolution, the definition of the vineyard areas, the data collected and their processing.

2.1 Definition of spatial and temporal resolution

2.1.1 Study area

The study area comprises the Canton of Ticino and the Moesa Region (Fig. 3). Both regions are located in the southern part of Switzerland. The Canton of Ticino has a surface area of approximately 2812 km^2 (BFS, 2020a, p. 58) and the Moesa Region of about 496 km^2 (BFS, 2020b); this means that the study area has a total surface area of about 3308 km^2.

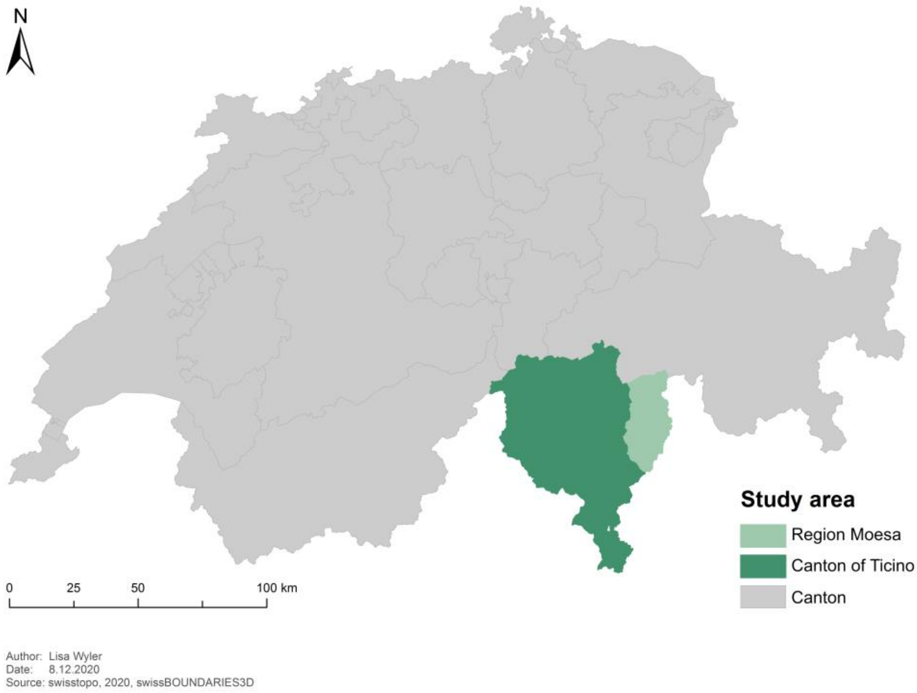

Figure 3 – Study area: Canton of Ticino in dark green, Moesa Region in light green and Switzerland with Cantons in grey.

The Canton of Ticino has a current population of 353'350 inhabitants (BFS, 2020a, p.58). The political division of the territory at municipality level is presently subjected to a merging action (fusion of municipalities). In 1990, the Canton of Ticino was divided into 243 municipalities, while in 2018 only less than half remains (115 municipalities) (Sezione degli enti locali, 2020). The land cover is represented by settlements (6%) and agriculture (13%) (BFS, 2020a, p.58). Forests (around 51%) cover half of the whole territory and unproductive surfaces (31%) cover the rest of the Canton's surface, mostly in the mountainous parts (BFS, 2020a, p.58).
The Moesa Region is one of the eleven regions of Canton of Graubünden and has 8670 inhabitants (BFS, 2020b). Settlements cover about 2% of the area, while agricultural land covers almost 12% (BFS, 2020b). Forests occupy about 48% and unproductive land about 39% (BFS, 2020b). The phenomenon of merging municipalities has also occurred in the Moesa Region, reducing the original 17 municipalities of 1990 to 12 municipalities in 2018.
I decided to keep the municipal structure of the study area as it was in 1990, because the phenomenon of merging municipalities has only recently had a great impact on the administrative divisions. Therefore, the former municipal structure influenced the wine-growing areas during the period analysed in this Master's thesis. Another advantage of the old municipal structure is that the Canton of Ticino and Moesa Region are divided into smaller and more homogenous entities. In contrast, the 2018 municipal subdivision includes, among others, large and heterogeneous municipalities, such as the municipality of Bellinzona, which merged together with 12 other municipalities in 2017, representing almost the entire Bellinzona district (Crivelli & Orelli, 2017). Moreover, the current structure of the municipalities will constantly change over time, as new merger projects are already planned (Sezione degli enti locali, 2021). Nevertheless, the data set of the municipality will also have the attribute of municipal divisions as in 2018, to allow also a possible analysis of the current political-administrative situation.

At present, the vineyards cover 1167.3 ha (Swiss Wine, 2020), i.e. 0.3% of the whole study area. Most of them (1122 ha) are located in the Canton of Ticino, the remainder (45.3 ha) in the Moesa Region (Swiss Wine, 2020). It should be noted that the values of agricultural statistics differ from those obtained by analysing data from cartographic representations (Krebs & Bertogliati, 2017). The vineyards of the study area represents 7% of the Swiss vineyard area (Ferretti, 2020). The annual wine production of about 6000 t or 55000 hl in 2019 is 5% of the national wine production (Ferretti, 2020) with 2855 winegrowers involved (SA, 2019). A particularity of this region is that only a part of the vineyards (700 ha) are managed by professionals. Whereas the remaining 400 ha are cultivated by mainly part-time vineyard-holders, who take care of very small vineyards during their free time (Bognuda, 2020).

2.1.2 Temporal windows

I selected three time windows to analyse the historical evolution of the area under vines in the study area of Canton of Ticino and the Moesa Region. The definition of these time windows is based on evolution of the vineyard surface area in southern Switzerland as reported by Krebs and Bertogliati (2017, Fig. 4).

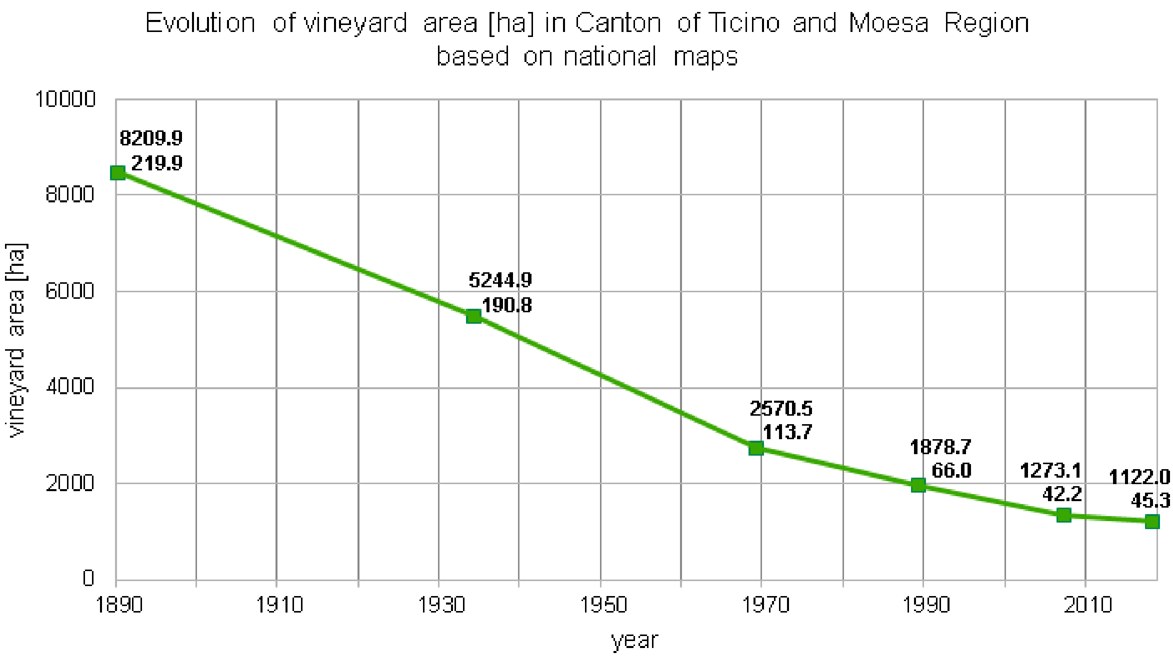

Figure 4 – Evolution of the vineyard area in Canton of Ticino and Moesa Region between 1890 and 2018 according to national maps in scale: 1:25000 (Krebs & Bertogliati, 2017, p. 50). For each point, information of the exact value of vineyard area in hectares in Canton of Ticino (top number) and Moesa Region (bottom number) is given.

The following three time windows and corresponding reference years were chosen:

- 1933-1938, year of reference: 1934
- 1987-1989, year of reference: 1989
- 2013-2018, year of reference: 2018

The term time window is due to the fact that the production and editing of a national map goes on for years, so they do not represent an exact moment in time, but rather a period. The choice fell on these three time windows because:

1. 1934 represents the first cartographically precisely documented point in the strong downward trend between the two World Wars. Moreover, the advantage of this time window over the 1890 time window is that it is easier to collect statistical data

2. The 1989 time window makes it possible to analyse the more recent slow decrease in vineyard area and represents an intermediary phase as the result of the first post-second World War period of socio-economic evolution. It also helps to formulate some hypotheses on the evolution of the near future.
3. 2018, as the most recent point with complete statistical data, is because it represents the current situation.

2.2 Definition of vineyard surface

On occasion of Krebs and Bertogliati’s research (2017), a digitalisation of vineyard polygons was carried out based on historical and national maps with the aim of estimating the evolution of the vine-growing area starting from the end of the nineteenth century. To obtain the data, they drew the polygons based on the cartographic representation of the vineyard, which has been adapted over the years as can be seen in Figure 3. Although the cartographic accuracy and representation style have changed over the years, regarding the three time windows analysed in this Master’s thesis, there are similar characteristics. The vineyards are referred to with the same map symbol (polygon containing short vertical segments). In the past they were black, today they are coloured in green.

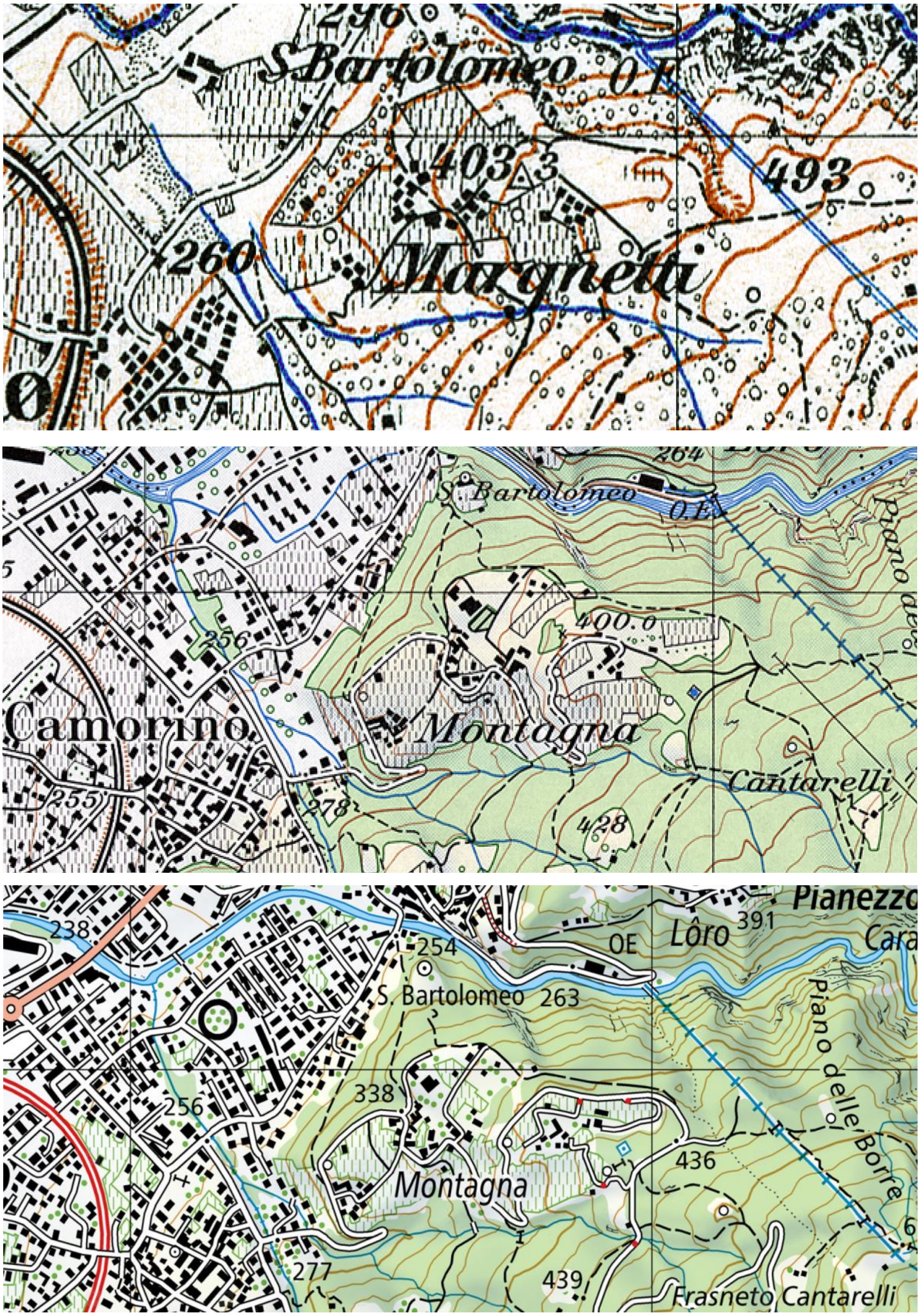

Figure 5 – Cartographic representation (from the top: 1934, 1989 and 2018) of vineyards next to the village of Camorino and in the neighborhood of the Montagna hamlet (Source: Swiss Federal Office of Topography).

From a historical and geographic point of view, digitised vineyard polygons offer a good estimation of the vineyard area, which is especially important for the period when there were no reliable statistics concerning land cover. Nevertheless, they also have some weaknesses to bear in mind. Firstly, vineyard polygons do not define any ownership relationships; therefore, an analysis cannot make any statements for particular vine-grower without further information (Fig. 6). Secondly, by definition, a map is an abstraction of reality and contains simplifications (Kohlstock, 2018). Thus, maps may depict some adjacent vineyards as a single polygon, even though in reality, for example, it may be that a small fence divides those vineyards, which are consequently owned by different people (Fig. 6). Furthermore, there is no differentiation in the representation of the vineyard according to the density of vines. Thirdly, the changing cartographic representations methods (Fig. 5) complicate the already difficult work of comparing the vineyard polygons over time even more. Finally, a map also contains place names and these can cover underlying topography such as vineyards. For the analysis of this Master's thesis, it means that the values of vineyard area are not exact as they contain some errors, but offer the best approximation, since no other geographical referenced data or model exist.

Figure 6 – Example of cartographic simplifications of ownership: in the map, only two vineyard polygons are represented, while in reality they are each one composed by two separated vineyards (Source: Swiss Federal Office of Topography).

2.3 Data collection

After the definitions of the spatio-temporal resolution and the original data for the vineyard information, the other original data sets had to be defined. Their detailed resources are listed in the section *10 Data sources of driving factors*.

The first collected data set is the raster swissALTI^{3D}. It is a digital elevation model from the Federal Office of Topography (swisstopo) with a high spatial resolution (2 m). Since the elevation has not changed over time, the raster of 2018 is suitable for all three time windows.

The other data sets concern the forest area. Since the forest area changes over time, one data set is needed for each time window. Swisstopo offers the topographic landscape model (swissTLM^{3D}), which contains a vector data set of the forest cover in 2018. The Swiss national maps and Siegfried maps are the basis for obtaining the vector models of the forest area for the first two time windows. The swissTLM^{3D} vector model also includes the building footprints in 2018. While the building footprints for the time window 1934 are provided through an extraction of the buildings from maps based on a method developed by Heitzler and Hurni (2020). Data of the building footprint are missing for the 1989 time window. Building zone data are only available for the last time window as a vector model from 2017. This model contains the representations of the different categories of building zones based on a harmonisation of the categories carried out by the cantons.

Some of the original data sets are only available at the municipality level. For all three time windows, through the various national censuses, there is the availability of the number of inhabitants and employees per economic sectors. Area values by land cover category are only available for the last two time windows (1989 and 2018), as land cover statistics have been carried out by swisstopo since 1979.

2.4 Conceptual Framework

To enable an analysis between time windows and between vineyards on the basis of a comparable unit of measurement, a cell of 1 ha in size is defined. Using the core application of ArcGIS (ArcMap version 10.4.1) and its tool *Fishnet*, I created a grid of cells with 100 m sides covering the entire study area. Cells intersecting the vineyard polygons in at least one time window are considered for further analysis as minimum mapping unit and will be referred to as *vineyard cells* in the remainder of the thesis. An example of this procedure carried out for vineyards in the year 2018 is shown in Figure 7. The cells make it possible to compare the heterogeneity of size and shape of the vineyard polygons by structuring them. Considering possible future analyses, it is easier to process cells than polygons. For example, it is less complicated to merge cells by assigning them to the relevant owner than to disaggregate vineyard polygons by property boundaries. The size of one hectare was chosen because it allows to obtain a significant number of vineyard cells (14309 cells), which intersect vineyards in at least one time window (Tab. 2). The possibility to use a higher spatial resolution was discarded because some statistical data have a spatial resolution corresponding to the municipal level and do not have a more precise georeferenced location.

In order to make the assignment of the data to the municipal level easier, I preferred to remove from the data set all the cells that intersect municipal boundaries in the year 1990. Finally, only cells that contain within them a total vineyard area of more than 100 m^2 are analysed, for not having to consider the high number of cells, which only intersect a small marginal part of the vineyards in the form of polygon slivers (i.e. very small and unwanted polygons). Considering that the smallest isolated vineyard surfaces represented on the national maps at a scale of 1:25000 are 166 m^2 in 1934, 90 m^2 in the 1989 and 174 m^2 in 2018, I concluded that no information of small vineyards is lost when discarding the cells with a vineyard area of less than 100 m^2.

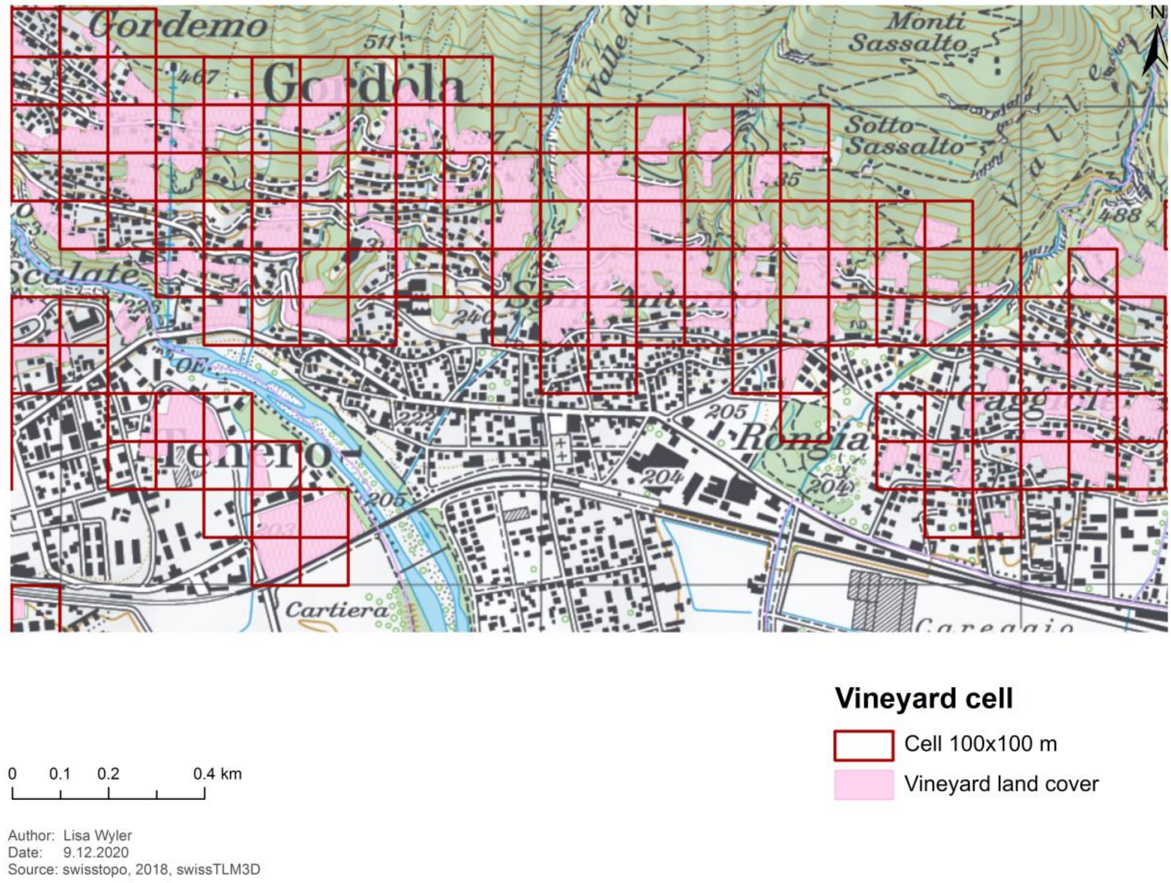

Figure 7 – Example of cells 100x100 m intersecting spatial polygons representing vineyard areas depicted on the Swiss national map (Source: Swiss Federal Office of Topography).

Table 2 – Number of cells 100x100 m^2 intersecting vineyards per reference year and after filtering municipality borders and vineyard area less than 100 m^2.

Reference year	Cells (1 ha) intersecting vineyards	Cells not intersecting borders	Cells with vineyard area > 100 m^2
1934	15106	13175	12397
1989	8300	7330	6638
2018	6324	5613	4942
TOTAL	29730	26118	14309

2.5 Data processing

The following paragraphs describe the methods used to obtain the data for each relevant driving factor divided by category and the rationale for their selection. All original data collected were processed to obtain values for the highest possible spatial resolution. This means that all values are relative to the individual vineyard cell. For the values with spatial resolution on the municipal level, the values are assigned to cells according to the municipality in the year 1990, where the cells are distributed. I chose to collect the data at cell or municipality level because it is easier for the analysis to aggregate the data to obtain data at a higher level of observation than the other way around.
Three applications were used for all operations. The operations on geodata were carried out with the core application ArcMap (version 10.4.1), while Adobe Photoshop CS was used to refine its outputs or to digitise land cover polygons. The last software is RStudio (R version 4.0.3) used to edit the socio-economic factor data sets and to visualise and analyse the results. In addition, any work with geographical data was done using the old Swiss LV03 coordinate system as spatial reference.
Figure 8 summarises the workflow of the data collection process. The yellow boxes describe the procedure carried out to obtain the one ha cells containing vineyard area in at least one time window. This procedure was explained in the section *2.2 Definition of vineyard surface*. While the section *10 Data sources of driving factors* is a detailed list of the primary data sources used to obtain the values of each factor.

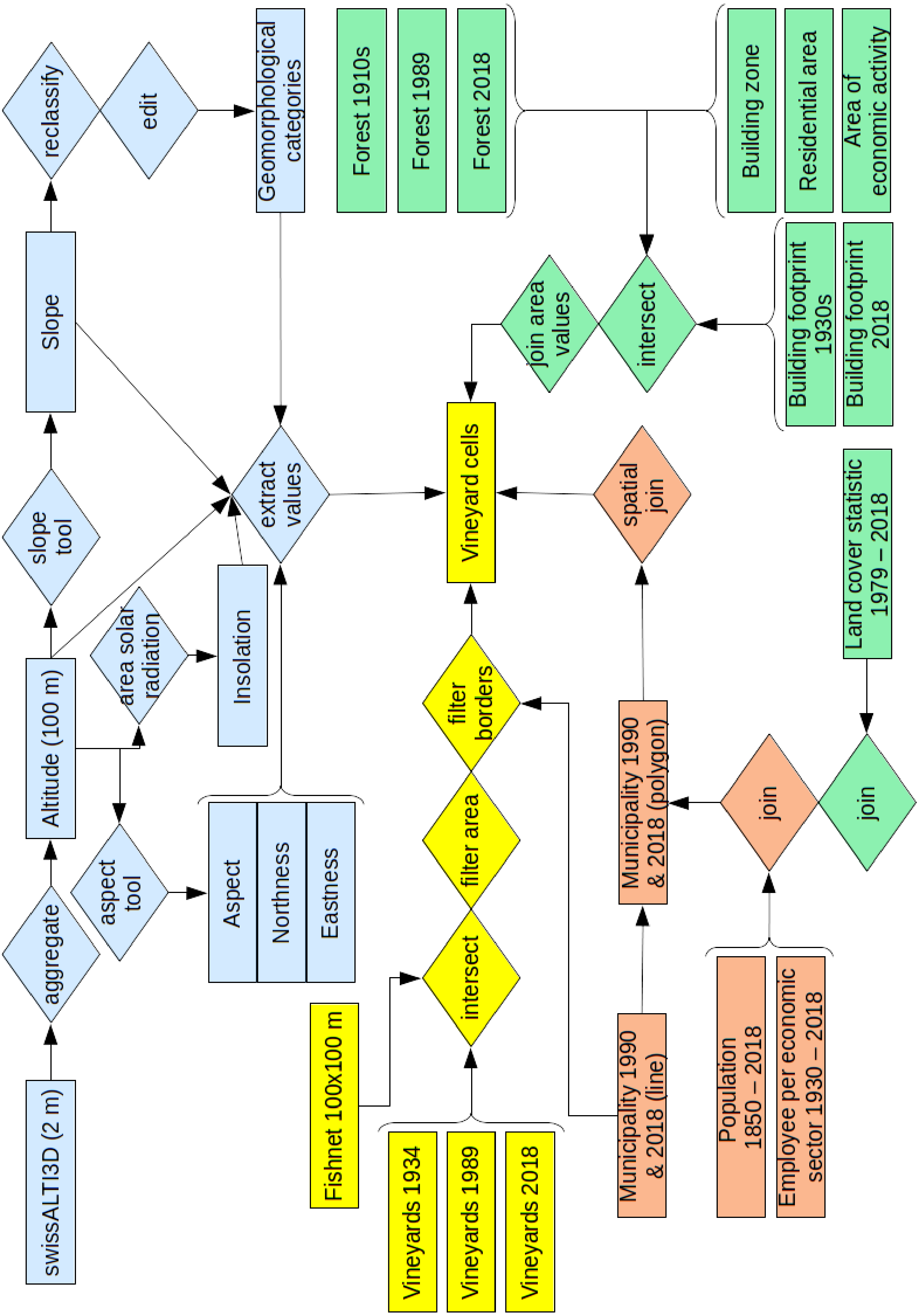

Figure 8 – Summary of the data collection workflow: preparation of the vineyard cells (yellow), geomorphological factors (light blue), land cover factors (green), and socio-economic factors (orange).

In order to find out what the possible relevant driving factors could be that influenced the evolution of vineyards in the study area and to prepare the data processing, it is necessary to define possible candidates. However, the availability of data and the possibility to adopt a simple method of data processing were also taken into account as selection criterion. Literature has also been a source of help and inspiration in determining possible candidates, in particular studies on the suitability of a region for viticulture (Liu et al., 2018; Irimia & Patriche, 2010). The definition of possible drivers is not exclusively limited to one type of factor. Therefore, the selected driving factors can be classified into three categories: geomorphological factors, land cover factors and socio-economic factors.

The first category containing the geomorphological factors was determined based on the literature on suitability studies. The purpose of such studies is to analyse the viticulture suitability of certain regions, which is determined especially on the basis of geomorphological factors, among others (Irimia & Patriche, 2010). Some studies use the term of oenoclimatic potential to refer at the suitability of a region for viticulture (Irimia & Patriche, 2019). The second category of land cover factors contains those factors that may represent pressure from other types of land cover. The selection of the land cover factors is based on a hypothesis of this Master's thesis: the abandonment and disappearance of vineyards in the lowlands is due to the construction of buildings (Liu et al., 2018), while at higher altitudes due to forest expansion and ungulate pressure (Burkhard, 2020). The last category of socio-economic factors contains those factors that represent the social transformation that has taken place at municipality level. These have been chosen on the assumption that population growth and the transformation into a society specialised in the tertiary economic sector gives less space to the agricultural area and consequently less space for vineyards.

The processed factors, obtained through the workflow (Fig. 8) are summarised in **Error! Reference source not found.** and the list of their detailed data sources is in the section *10 Data sources of driving factors*. For each factor, the type of value, the reasons for the selection, is indicated.

Table 3 – Summary of selected driving factors by category, motivation for selection, data structure, collection method and possible challenge.

DRIVING FACTOR	MOTIVATION	METHOD & DATA STRUCTURE	CHALLENGE
<u>Geomorphological factors</u>			
Altitude	Influence on vineyard distribution	• Value per vineyard cell [m] • ArcMap "Aggregate" tool from 2 m to 100 m	Choose the aggregation method

Slope	Influence on mechanisation and management difficulties	• Value per vineyard cell [°] • ArcMap "Slope" tool	Choose the aggregation method
Aspect →northness, eastness	Influence on vineyard distribution and productivity	• Values per vineyard cell [-1, +1] • ArcMap "Aspect" tool • ArcMap Raster calculator to rewrite values	Choose the aggregation method
Insolation	Influence on vineyard distribution and productivity	• Value per vineyard cell [WH/m^2] • ArcMap "Area Solar Radiation" tool	Choose the aggregation method
Geomorphological category	Influence on vineyard distribution and mechanisation	• Surface area per geomorphological category per vineyard cell [m^2]	Digitalisation of categories filtered by slope in Photoshop
Land cover factors			
Forest	Sign of pressure from other land covers and of abandonment	• Geodata for the years 1910s, 1989, 2018 • Forest area inside vineyard cells • Changes in land cover in R	Digitalisation and colour extraction from Siegfried and national maps in Photoshop
Building Zone	Sign of pressure from other land uses	• Geodata for 2017 • Building zone area inside vineyard cells • Vineyards within the building zones • Different categories of building zones	Geodata of building zones only for 2017
Building Footprint	Sign of urbanisation and pressure from other land uses	• Geodata for 1930s and 2018 • Base area of building inside vineyard cells • Changes in building area and counting per municipality in R	• Geodata only for two time windows • Extraction errors from Siegfried maps

Land Cover Statistic	Sign of pressure from other land cover categories	• Statistics of 27 land cover categories per municipality for the four time windows 1979-85, 1992-97, 2004-09, 2013-18 • Surface changes by category and municipality in R	• Statistics since 1979 • Estimation of missing values of pre-aggregation municipalities in R • No spatial reference of where changes took place
Socio-economic factors			
Population → density	Sign of urbanisation (more people need more space)	• Values per municipality since 1850 every decade • Change of inhabitants per decade in R • Change in population density per decade in R	• Expansion into other land use categories and not vineyards • Estimation of missing values of pre-aggregation municipalities in R
Employees by economic sector	Sign of social transformation, mechanisation and fewer jobs in primary sector	• Values per municipality since 1930 every decade • Changes in employees per decade in R	• Each economic sector comprises a multitude of employments and shows a general trend • Estimation of missing values of pre-aggregation municipalities in R

2.5.1 Geomorphological factors

The process used to obtain the values for the geomorphological factors is represented by the blue boxes in Figure 9.

As first possible influencing factors, the altitude was processed, as other factors are linked to it. In order to obtain a single value per vineyard cell, the values of the Swiss digital elevation model (swissALTI3D) were aggregated from 2 m to 100 m by extracting the median value. Altitude can have an influence on the distribution of vineyards over the territory, as generally in the study area higher altitudes are equal to areas that are more mountainous. Therefore, accessibility is usually more complicated, temperatures are lower and the topography is steeper. It is possible to notice that in the study area there are no vineyards over 1000 m of altitude.

Based on the output altitude raster and the *Aspect* tool in ArcMap, the aspect factor values were calculated. These values were then rescaled to obtain the values of northness and eastness through the following two transformations (Eq. 1):

$$northness = \cos\left(aspect * \frac{\pi}{180}\right)$$
$$eastness = \sin\left(aspect * \frac{\pi}{180}\right)$$

Equation 1 – Equations for scaling aspect values to northness (first from top) or to eastness values (second from top). Simply enter the values instead of aspect, to obtain the scaled values.

The transformations give values between (–1) and (1), which corresponds to the north in case of northness, while it corresponds to the east in case of eastness. These values are more suitable for calculation as they are linear as opposed to the original aspect values. The exposition of the hillsides could be a relevant factor for its possible influence on the distribution of vineyards and its productivity, as north-facing hillsides are less attractive for vineyards as the insolation is less strong, especially in steep valleys.

The altitude raster is also the basis for estimating insolation values using the A*rea solar radiation* tool. An average value [Wh/m^2] per vineyard cell from a 10 m area solar radiation raster were calculated. As insolation correlates with slope and aspect, it can have an influence on the distribution and productivity of vineyards too.

To calculate the slope values, the ArcMap S*lope* tool was used on the elevation raster. For each vineyard cell a value in degrees from a slope raster (100 m cell size) was extracted. Slope is possible Possible factor due to its influence on management and mechanisations difficulties. Steep terrain affects vineyards with multiple problems: harder physical work, lower earnings, less attractiveness for new generations (Burkhard, 2020; WSL, 2019). Moreover, a mechanisation of these areas is sometimes only possible by terracing.

The last geomorphological factor are the geomorphological categories, which comprise seven different categories (Tab. 4) and are the same categories used in the study analysing vineyard management difficulties in the Bellinzona, Moesa and Locarno regions (WSL, 2019). This factor could describe the distribution of vineyards over the territory and their potential for mechanisation, as the categories correlate with the slope. To define the geomorphological categories over the whole study area, the slope raster was reclassified to obtain a raster representing the plains and a raster representing the debris cones. Those two raster were then edit in Photoshop by cleaning the noise, correcting errors and simplifying the two categories. The decisions made to determine whether a certain part of the territory was plain or debris cone, were made based on cartographic maps and personal knowledge of the terrain. The knowledge of one of my supervisor (Patrik Krebs) was also helpful. The output of this clean-up was then again combined in ArcMap with the other layers representing the other categories, also determined through reclassification of the slope. Prior to this, the transition category was added by rasterising the output of the B*uffer* tool. Figure 9 represents the final output of the distribution of the geomorphological categories over the study area. This raster output with a cell size of 10 m was used to calculate the area of each geomorphological category that intersects vineyard cells, to describe the terrain morphology represented inside the vineyard cell.

Table 4 – Definition of geomorphological categories.

Number	**Category**	**Definition**
0	Lake	Water surface surrounded by land
1	Plain	Valley floor and slope less than 4°
2	Debris cone	Debris cone in the valley floor with slope between 4-16°
3	Transition	50 m wide belt (horizontal projection) between debris cone or plain and slope
4	Glacier terrace	Area with slope less than 20° on hillside
5	Hillside	Area with a slope higher than 20° on hillside
6	Over 1000 m	Area over 1000 m of altitude and without vineyards

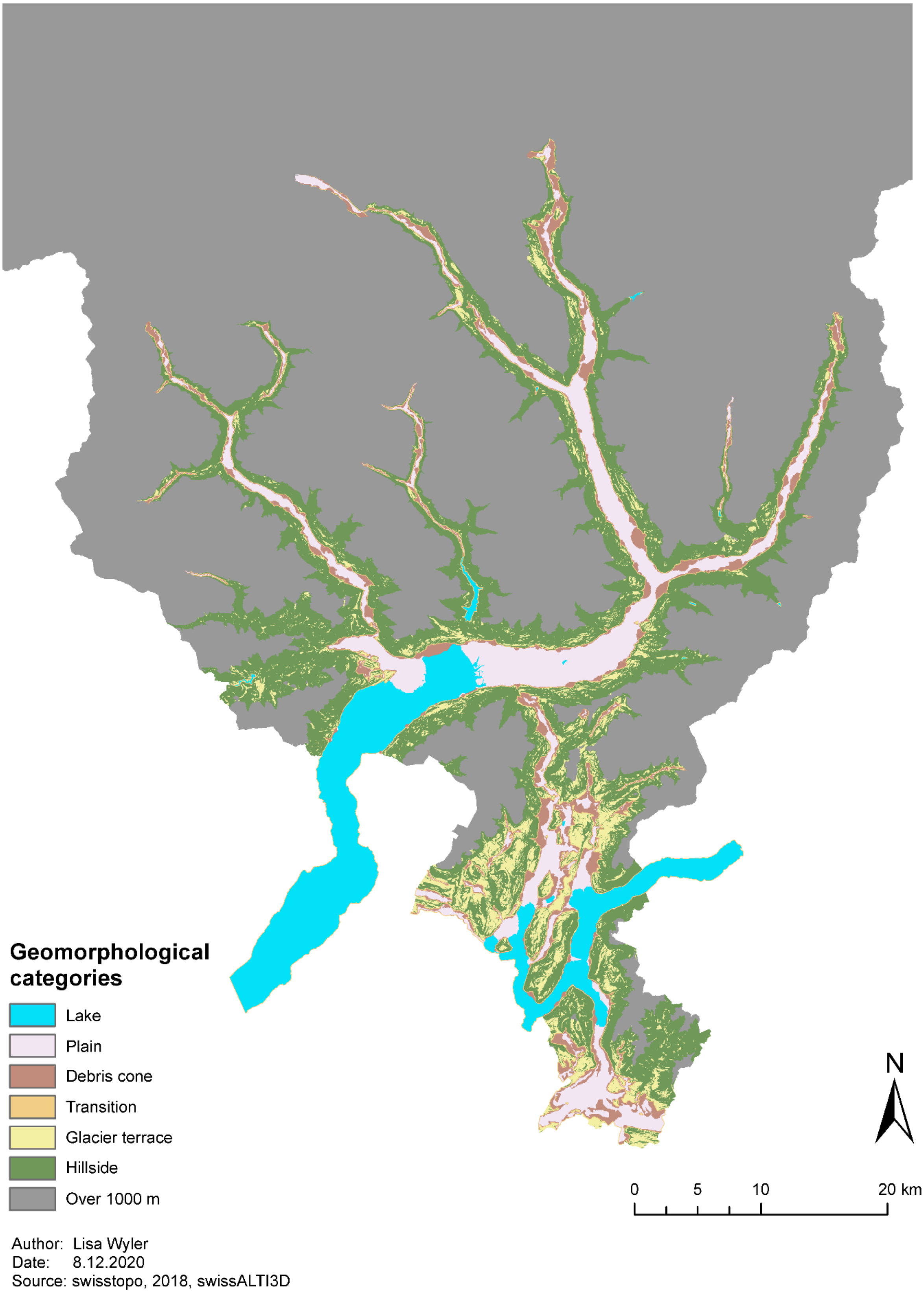

Figure 9 – Distribution of the geomorphological categories over the study area, showing the structure of the valley through the territory.

2.5.2 Land cover factors

The workflow for the collection of land cover factor data is represented by the green boxes (Fig. 6). For all land cover factor data, it must be considered and remembered, that they contain uncertainty and errors.
The first factor consists of the forest area in square metres within each vineyard cell calculated from the intersection area of the two polygon data sets in ArcMap. This factor includes forest polygons in three periods: 1910, 1989 and 2018. Forest may be a sign of pressure due to the difficulties of managing the boundaries between vineyard and forest. In addition, it is a possible land cover class, which could occupy the space of abandoned vineyards. The 2018 forest vector data set is the most accurate of the three, because it is the recent one and is based on the land cover model produced by the Federal Office of Topography. While supervisor Patrik Krebs produced the data set of the forest area in 1989 by extracting the different shades of green from national maps of this period. Furthermore, he cleaned and simplified the output with help of Adobe Photoshop. The forest area in 1910 for the Canton of Ticino was already available from the WSL. Therefore, I completed this data set by applying the same methods used to compute the part of the Canton of Ticino. More precisely, I digitised the forest area for the Moesa Region based on the Siegfried maps of that period, outlining the forest symbols in Photoshop.

The second factor concerns the building zones for the year 2017. The data set is the result of a harmonised representation by the Swiss cantons. This factor was also used to calculate the area in square metres within the vineyard cells by intersecting them. In particular, residential areas and economic activity areas were selected by attribute in order to also calculate their area within the vineyard cells. The selection of these two specific zones is based on the assumption that they might be the two dominant zones, which have expanded the most in the last century. Furthermore, the organisation of building zones is a reflection of the political idea of spatial planning in a region. In this case, building zones may have an influence on the distribution of vineyards and represent a potential pressure.

The third factor is the building footprints, of which there are two vector data sets. The first represents the building footprints from the 1930s. They were extracted from the Siegfried maps of this period based on the method developed by Heitzler and Hurni (2020). The second data set contains the 2018 building footprint and is a vector model produced by the Federal Office of Topography. These two factors were used to calculate the area and number of buildings within the vineyard cells by intersecting them. The values of the basal area of the buildings and their number have increased over time and could probably occupy the vineyard space.

The fourth and last factor is the land cover statistic, which represents the area values in hectare per land cover category at municipal level. I chose to process the data sets describing 27 land cover classes because they contain the vineyard class as a specific category. All values were collected in occasion of the "Arealstatistik" done by the Federal Office of Topography for four periods: 1979-85, 1992-97, 2004-2009 and 2013-2018. This factor shows the changes in land cover over time, reporting for the specified windows the relative current situation. The data were four tables, which were processed and imported in RStudio. Since the list of municipalities was updated for each period, the tables for the last three periods do not contain all municipalities from 1990. Therefore, I chose to estimate the values for each land cover class for the missing municipalities with the following equation (Eq. 2):

$$\frac{L_{T,i}}{T} = \frac{L_{A,i}}{A} \leftrightarrow L_{A,i} = \frac{L_{T,i}}{T} * A$$

Equation 2 – Equation to estimate missing values of a specific land cover class ($L_{A,\,i}$). Based on the proportion between the area of the same specific land cover class of the merged municipality ($L_{T,\,i}$) and the area of the municipality (T). This value multiplied by the area of the single municipality (A).

This equation (Eq. 2) is a simple way to obtain a possible value of the land cover area for the missing municipality. Although it has the weakness, it is based on the assumption that the proportion between the area of a specific land cover and the area of the merged municipality is the same for all the single municipalities.

2.5.3 Socio-economic factors

The orange boxes in Figure 8 summarise the workflow of data collection of the socio-economic factors. This category consists of two factors. These two factors, the population and the employees by economic sector have the spatial resolution of the municipality level.
The factor population was chosen as researches have shown that the human being is currently the main driver of land cover change (Liu et al., 2018). The population from 1850 to 2018 for municipalities structured as in 1990 results from the combination of three different population tables. These three tables were modified with RStudio. The first table contained the population values for the 243 municipalities in 1990. The second table included values for municipalities in 2010, and the third table for municipalities in 2018. As already mentioned, there have been frequent mergers of municipalities in the last decade, so the second and third tables were missing some data. In order to

avoid these missing data, first of all it was important to know which municipality has been merged since 1990. In other words, it was important to know which municipalities merged into which new or larger municipality and when it happened. The year of merger was significant to know, as the structure of the municipality in 2010 was different from that in 2018. Therefore, the second and the third table contained different municipalities. From 1990 to 2010, 22 municipalities merged in the Canton of Ticino. Since 2010, there have been two mergers in the Moesa Region and ten in the Canton of Ticino. In the case of mergers, I assigned the same number to each municipality with missing data. This number was useful to perform a loop in RStudio to estimate the missing population values. The following equation (Eq. 3) was used to make the estimations:

$$\frac{P_{i-1}}{T_{i-1}} = \frac{P_i}{T_i} \leftrightarrow P_i = \frac{P_{i-1}}{T_{i-1}} * T_i$$

Equation 3 – Equation to estimate the missing population values of a single municipality (P_i). Based on the proportion between the inhabitants of the previous decade of the single municipality (P_{i-1}) and the sum of the population values of the merged municipalities in the previous decade (T_{i-1}) multiplied by the total population of the merged municipality (T_i).

As can be seen, the equation calculates with a proportion between the value of inhabitants of a single municipality and the values of the merged municipality. The estimation of the missing population values is based on the assumption that the proportion remains unchanged over time, although there is no certainty, and therefore a single municipality may have a different evolution than the merged municipality. Although equation (Eq. 3) represents a simple method to avoid missing data. Finally, the final values of the inhabitants assigned to each vineyard cell were also used to calculate the population density values over the area of the municipality below 1000 m altitude, since vineyards and society are mainly located in this region.

Research has shown (Krebs & Bertogliati, 2017; Panzera, 2017) that the evolution of vineyards has changed with the transformation of society, as a society based on the tertiary economic sector has other needs and offers fewer jobs in the other two economic sectors, making them less attractive. Therefore, I also processed the data to obtain the number of employees per economic sector, although the original data for this factor also had the problem of containing missing values. The data set is the result of the combination of seven different tables. Four tables are transcriptions of the tables represented in the census documents for the years 1930-1960. The fifth table included values for the decades between 1970 and 2000. The sixth table contained values for 2008 and the last one for 2017. These seven tables have been modified and imported in RStudio. The data sets for the years 2008 and 2017 contained missing data because the list of municipalities was updated from time to time. Therefore, I again used an equation (Eq. 4) to estimate the values of employees by economic sector.

$$\frac{E_{i,j-1}}{T_{i,j-1}} = \frac{E_{i,j}}{T_{i,j}} \leftrightarrow E_{i,j} = \frac{E_{i,j-1}}{T_{i,j-1}} * T_{i,j}$$

Equation 4 – Equation to estimate the missing values of employees per economic sector for the municipalities before merger ($E_{i,j}$). The index i is indicating the economic sector, while the index j indicates the year of the decade. The proportion is between the employees per one specific economic sector of a single municipality of the decade before and the sum of all employees of that specific economic sector of the merged municipalities. This value is then multiplied by the total values of employees per specific economic sector of the actual decade of the merged municipality.

As in the situation of estimating the values of the population, each municipality with missing values got a number like the others that were merged together depending on whether the estimation was done for the year 2008 or 2017. This equation (Eq. 4) has the same deficit as the one used for the population data (Eq. 3), because it is based on the assumption that the proportion remains the same over time, even though it is possible that a single municipality has a different evolution of employees per economic sector as the merged municipality.

These two factors, population and employees per economic sector, were imported into ArcMap by joining the data set tables with the attribute table of the municipality shapefile. This file contains the municipality borders of 2018 plus the old boundaries of 1990 within the merged municipalities and its attribute table contains the attributes of the municipality name in 1990 and the name in 2018.
The vineyard cells obtained information about the municipality, where they are located, the values of population and the employees by economic sector through a spatial join. Since the vineyard cells that crossed municipality borders are not considered, the assignment of those values was unique.

2.6 Analysis methods

The analysis will be carried out on the basis of the attribute table of the final dataset containing information for each cell that at least in one time window intersected some vineyard area. All attributes in the table are listed in Appendix 11.1.
The methods of analysing the data collected for this Master's thesis are mostly descriptive in nature, as the collection of the data took most of the work. This is due to the fact that no work or research had previously been done to describe all the vineyards in Canton Ticino and the Moesa Region in the last century. In particular, no research has been carried out on the structure and distribution of vineyards and related factors. In addition, the data collected had various forms and had to be compiled and edited to merge them.
The analysis consists of answering the main research question on how the vineyards have evolved, visualising the change between time windows and its distribution over the study area. This analysis

will be carried out at different spatial resolutions, since the morphological characteristics change a lot over the whole territory of the study area. In fact, the southern part of the study area, locally called Sottoceneri, i.e. below Mount Ceneri, includes the districts of Lugano and Mendrisio and the morphology of its terrain is less mountainous and the general altitudes are lower than in Sopraceneri (i.e. above Mount Ceneri). This phenomenon can also be observed in Figure 7.

In order to answer the second research question on what are the possible driving factors, the analysis shows how the factors have changed over time and how they are related to the change in vineyards. Here it is important to take into account whether the factors change over time or not and whether they need to be adapted. For example, altitude values are based on one raster altitude, while forest area values have to be correlated according to years and time windows.

The two applications, RStudio and ArcMap, are used to visualise and analyse the data. In summary, it can be said that the results of the analysis will be in the form of maps and graphs, which will be described. The purpose of the description will be to find an answer to the research questions and to confirm or think up new hypotheses.

In addition, I will apply the Random Forest (RF) algorithm (Breiman, 2001) to analyse the driving factors also with a statistical method. The algorithm will be used in two ways, as variable selector and as regression method, as it provides indications of the importance of individual variables. The aim of applying RF is to analyse which variables most influence the vineyard area of each time window and the change in vineyard surface between the time windows. In order to select the variables, I apply RF to most of the variables, which are manually selected based on a temporal correspondence and the starting point and change. For example, to the select the variables describing the change in vineyard area between 1934 and 1989, I apply RF, among others, on the population values of 1930 and the population difference between 1930 and 1990. Afterwards, I keep only those with an importance greater than a specific value (value greater than 30 of increase of mean square error). These variables will then be used to re-run RF to analyse the most important variables in more detail.

3 Results

3.1 Vineyard evolution

Before analysing which are the relevant driving factors influencing the evolution of vineyards since the 1930s, it is important to characterise the evolution itself. Appendix 11.1 reports all available data concerning the presence of the vineyards in the different considered periods. In the time window 1934, the vineyard area was nearly 4800 ha, while about 1730 ha in 1989 and 1073 ha in 2018.
Vineyard cells are mostly distributed on the main valley floors (Fig. 10). They are therefore overall located from north to south, although the density is higher in Sottoceneri, the southern part of Canton Ticino. Urban areas, such as Locarno, tend to display a stronger decrease in the vineyard area. Another peculiarity is the shift from higher altitude ranges down to the lowlands observed in some particular areas such as the slopes around the Piano di Magadino.
Figure 11 shows that the median area of vines per cells decreased over time in all eight districts of Canton Ticino and the Moesa Region. In addition, the overall variance of the vineyard area also decreased, even though all districts have cells that are at least the half (i.e. 5000 m^2) covered by vines. This means that in each district there are single or multiple vineyards that exceed 5000 m^2.

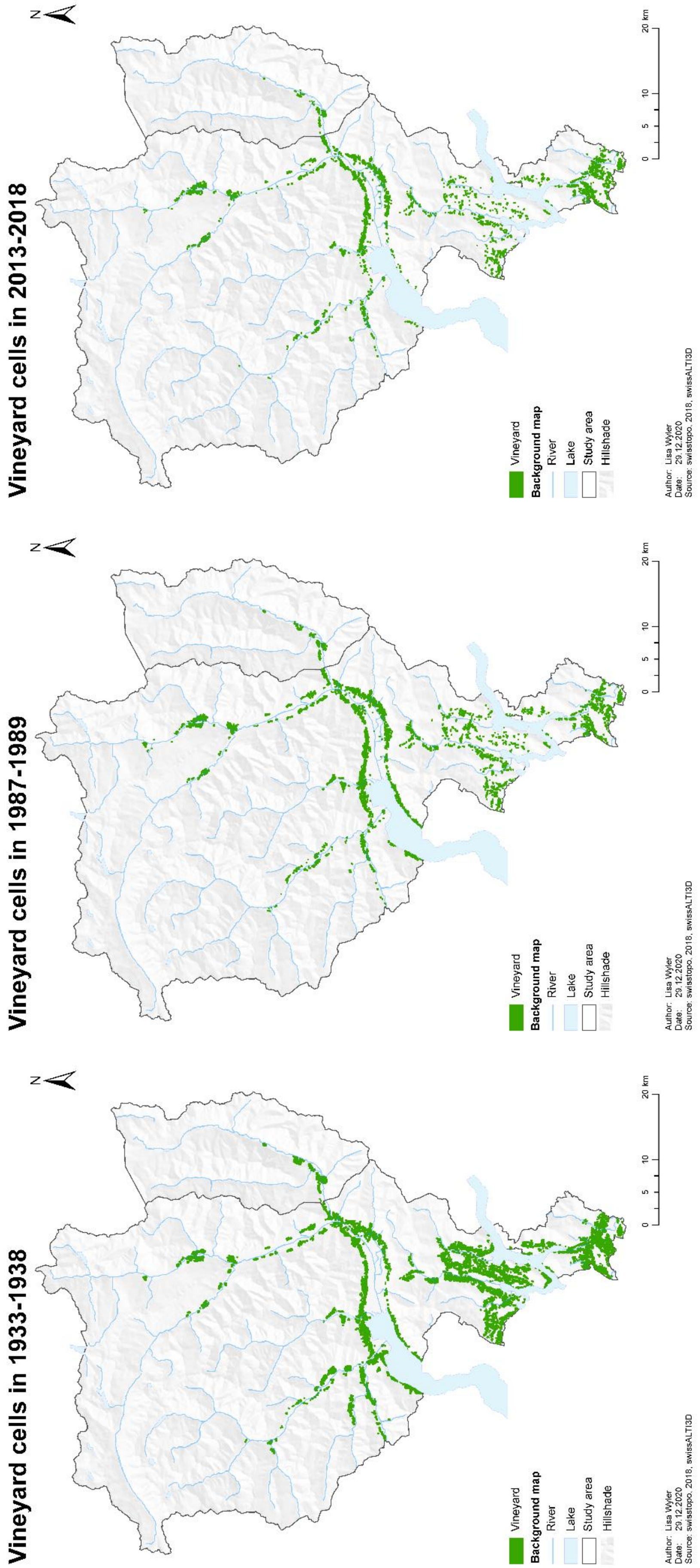

Figure 10 – Distribution of the vineyard cells in the periods 1933-1938, 1987-1989 and 2013-2018.

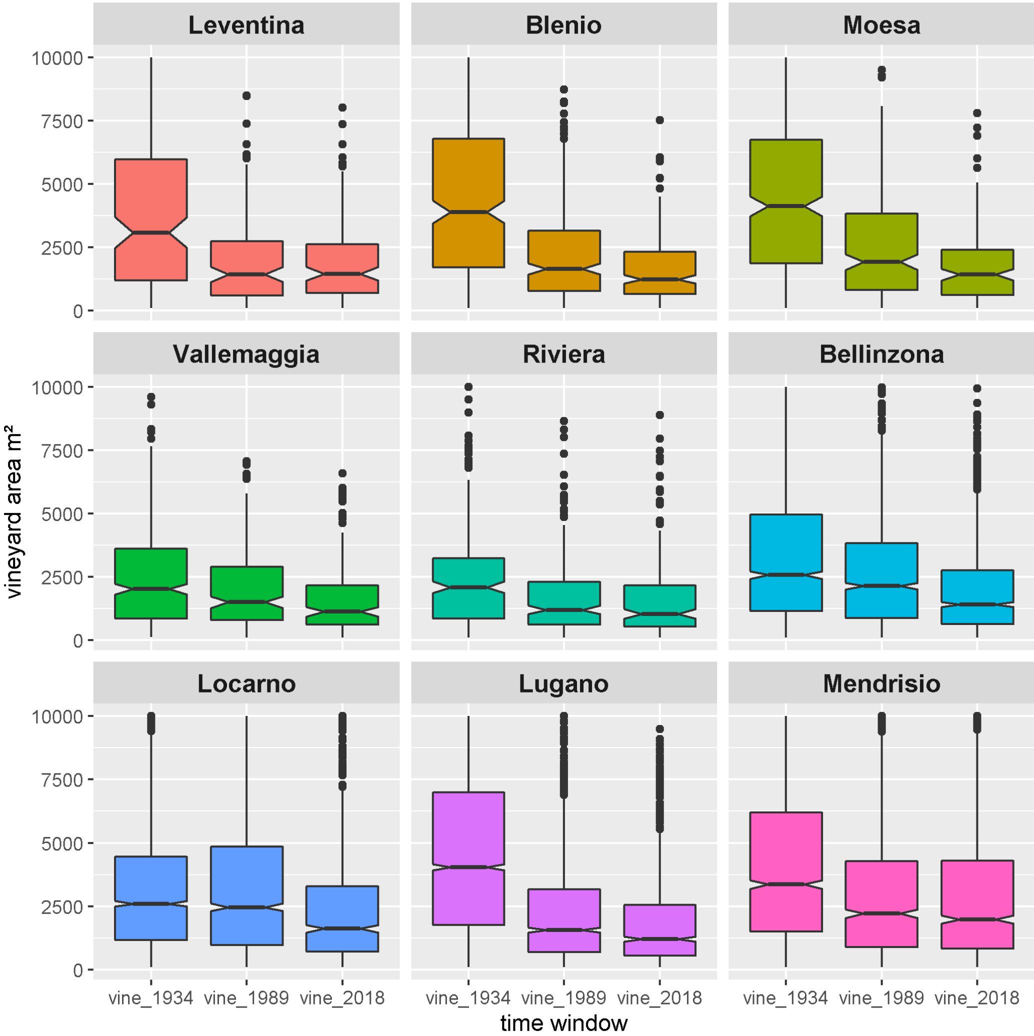

Figure 11 – Variance in vineyard area [m²] inside cells over time windows at district level.

Figure 12 reports the evolution of the vineyard area at municipality (status 1990) level. In general, there is a widespread trend of decrease in the vineyard, but there are some extreme cases. For example, the municipality of Novazzano (blue line in the district of Mendrisio) had the largest vineyard area of this region in 1934 (nearly 150 ha), but displayed the greatest absolute decrease since then. A similar trend is visible for the municipalities of Roveredo (pink line in the Moesa region), Bellinzona (orange line in the Bellinzona district) and Gordola (green line in the Locarno district). The municipality of Biasca (orange line in the district of Riviera) is the only one displaying a reverse trend resulting in a noticeable increase of vineyard cultivation, although with very small number in absolute terms.

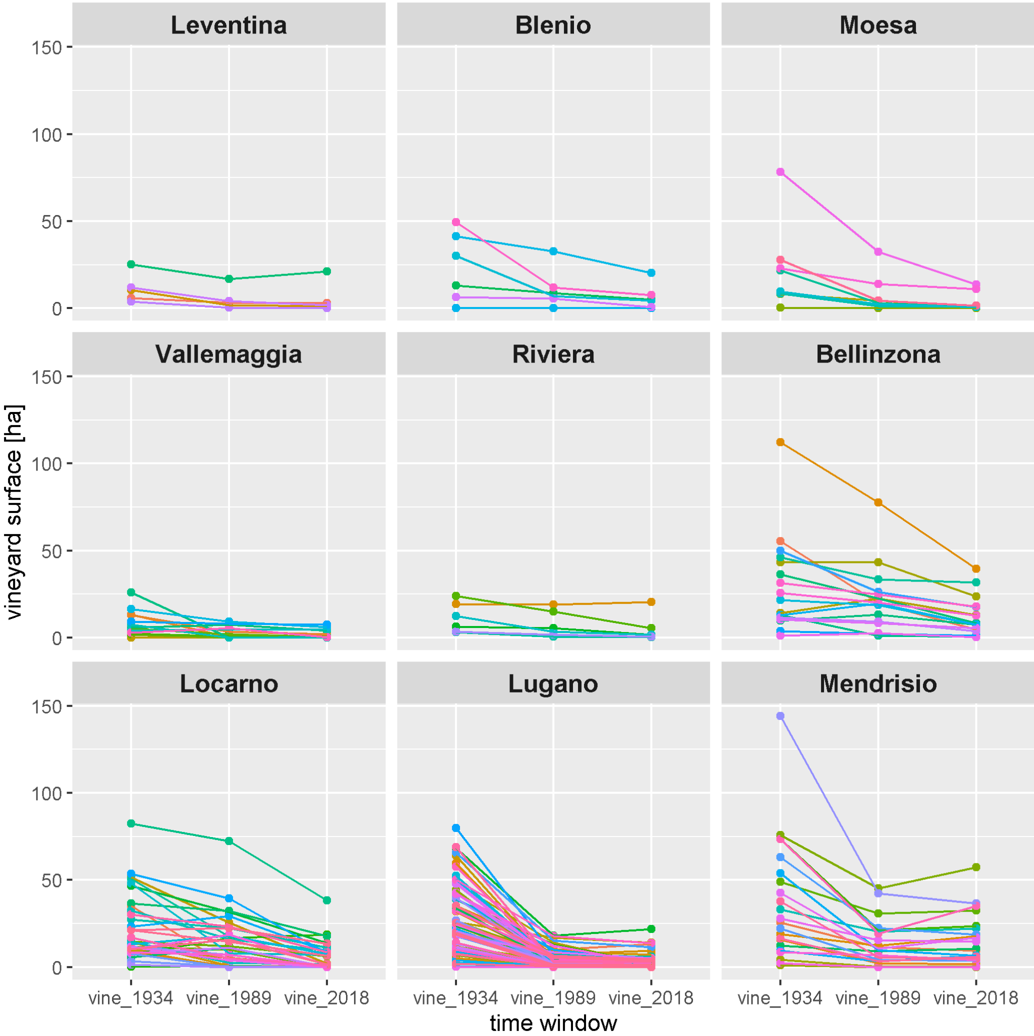

Figure 12 – Evolution of the total vineyard area [ha] per municipality (status 1990) in each considered administrative district.

Figure 13 shows the evolution of the vineyard area at cell level. As a general trend, vineyards in 1934 were larger than in the subsequent periods, what is clearly highlighted by the peak of the10’000 m^2 cells fully covered by vineyards. The 2018 distribution reveals the opposite extreme, highlighting the strong decrease of the number of cells with high vine coverage. Vineyards have thus generally become smaller over the study period.

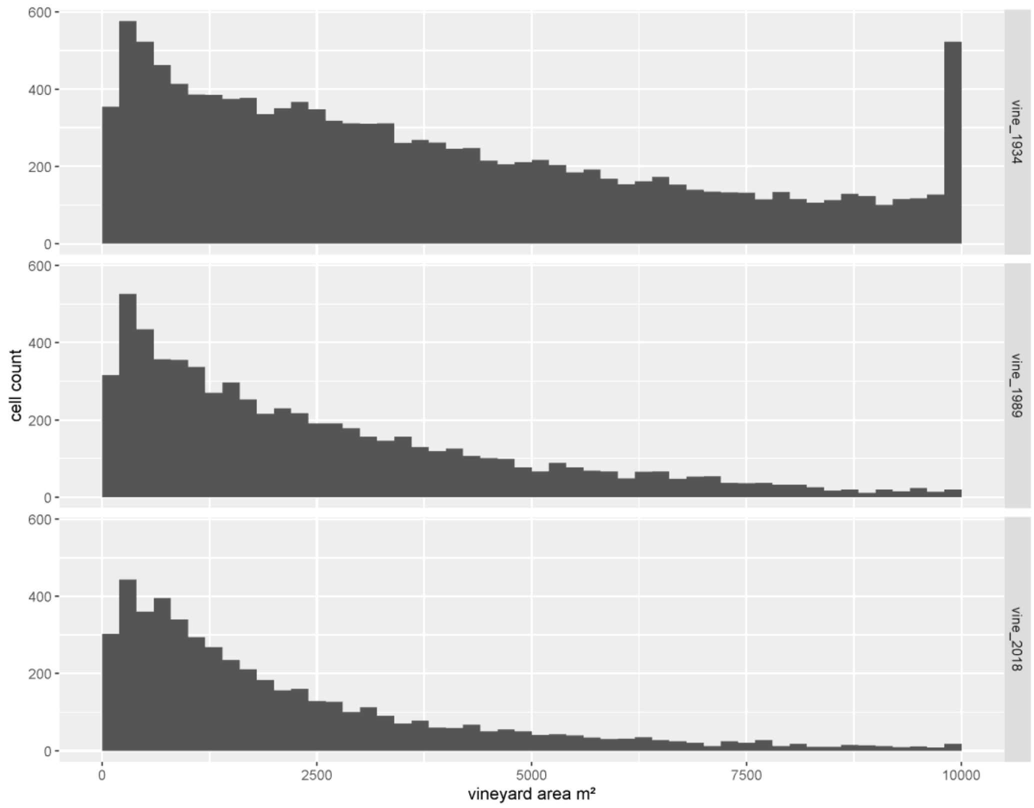

Figure 13 – Evolution of number of cells per vineyard area [m²] over the considered time frame..

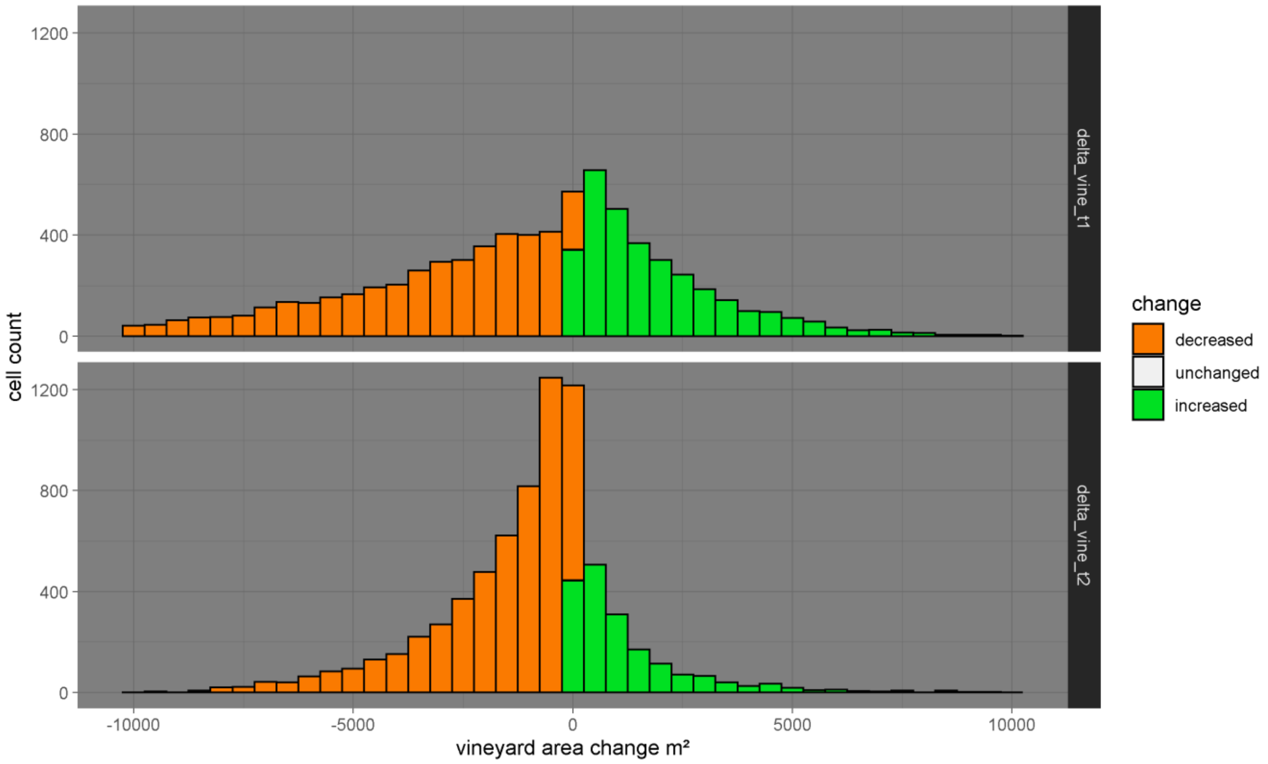

Figure 14 – Number of cells per vineyard area change [m²] in the periods 1934-1989 (top) and 1989-2018 (bottom).

Changes in vineyard area at cell level between 1934 and 1989 (Fig. 14) are more frequent over all vineyard area values and the cases of increase are more than in the second period (Tab. 5). In contrast to the evolution in the period 1989-2018 reports higher frequency of decreases especially for cells only partially covered by vineyards.

Table 5 – Contingency tables for the periods 1934-1989 (first table) and 1989-2018 (second table) showing the number of cells for the possible changes scenarios in vineyard area inside cells.

		1989			
		decrease	increase	unchanged	sum
1934	no vine	0 (0%)	1564 (81.8%)	348 (18.2%)	1912
	vine	10776 (86.9%)	1619 (13.1%)	2 (0.0%)	12397
	sum	10776 (75.3%)	3183 (22.2%)	350 (2.4%)	14309

		2018			
		decrease	increase	unchanged	sum
1989	decrease	2780 (25.8%)	1344 (12.5%)	6652 (61.7%)	10776
	increase	2670 (83.9%)	511 (16.1%)	2 (0.1%)	3183
	unchanged	2 (0.1%)	348 (99.4%)	0 (0%)	350
	sum	5452 (38.1%)	2203 (15.4%)	6654 (46.5%)	14309

The analysis has already shown that the evolution of the vineyard was not the same in the period 1934-1989 as in the period 1989-2018. These differences also appear when analysing the geographical distribution of the evolution (Fig. 15). Between 1934 and 1989 there was a decrease in the area under vines near the developing urban areas, such as Locarno, and in the southern part of Ticino, and an increase in the southern coast of Lake Maggiore (i.e. in the zone of Gambarogno). Where before there was an increase, afterwards there was the strongest decrease in the period 1989-2018, while in the southernmost part of the canton there was a slight increase (especially in the Mendrisio district). Looking at the general evolution between 1934 and 2018, some small vineyard reconstruction projects can be seen, although the general picture is the decrease of vineyard area. Finally, one of the first observations made when looking at the distribution of the vineyard cells (Fig. 10) is also confirmed the "shift" towards the valley floor around the Piano di Magadino.

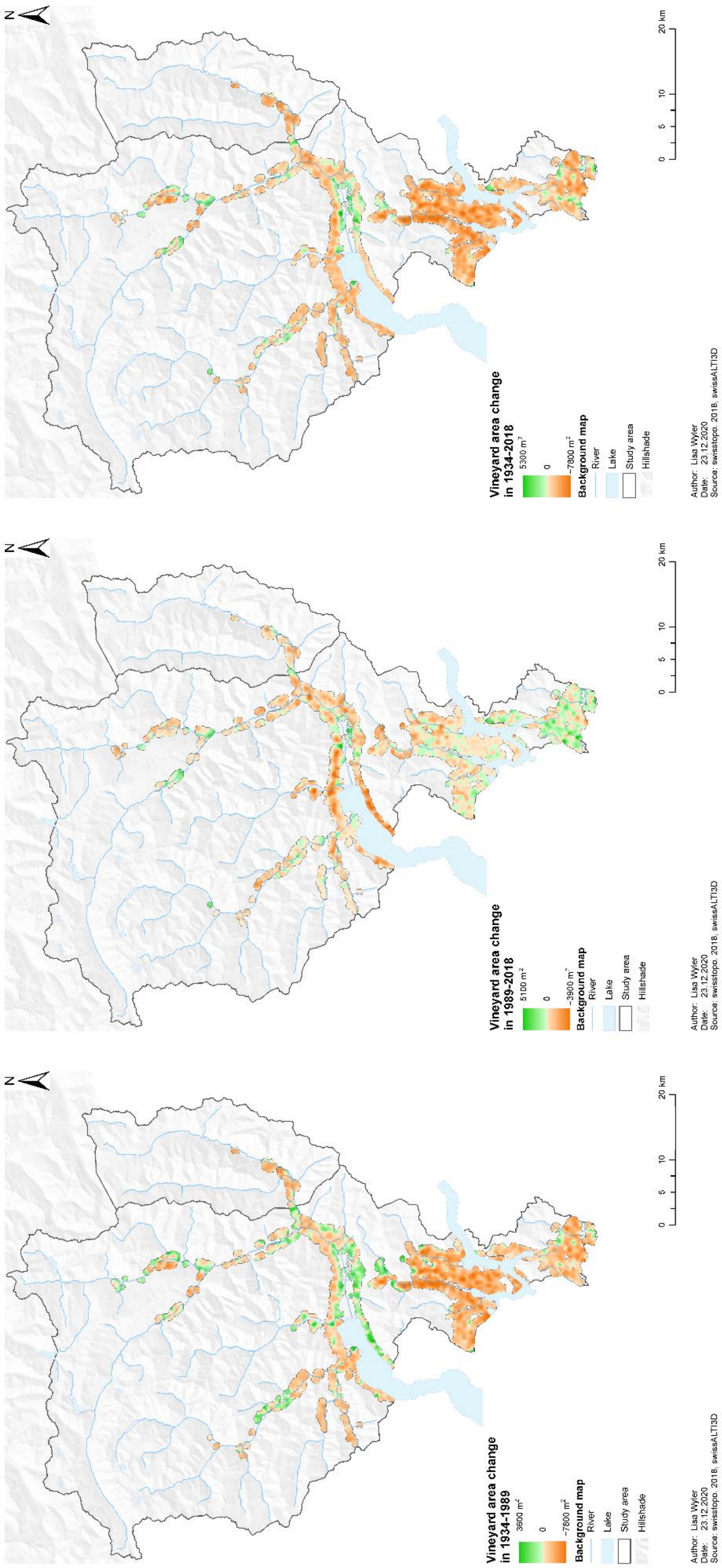

Figure 15 – Maps showing decrease (orange) and increase (green) in vineyard area inside cells in the periods 1934-1989 (bottom), 1989-2018 (middle) and 1934-2018 (top). Values and size of cells enhanced with focal statistics in order to reduce noise and optimise the visibility of general trends.

3.2 Characterisation of the vineyard cells composition

By analysing the composition of the vineyard cells in terms of geomorphological categories (Fig. 16) it can be seen that the vineyards are distributed over all geomorphological categories and this over all time windows. Although, where vineyard cells were more frequent at the starting time window (1934), that is the lowlands, debris cones, glacier terraces and hillsides, there were also more losses in the subsequent periods. In all time windows, about half of the vineyard cells are located in areas where management is easier (lowland and debris cone), because accessibility is greater. The other half are located where accessibility is less and management is more difficult (glacial terrace and hill).

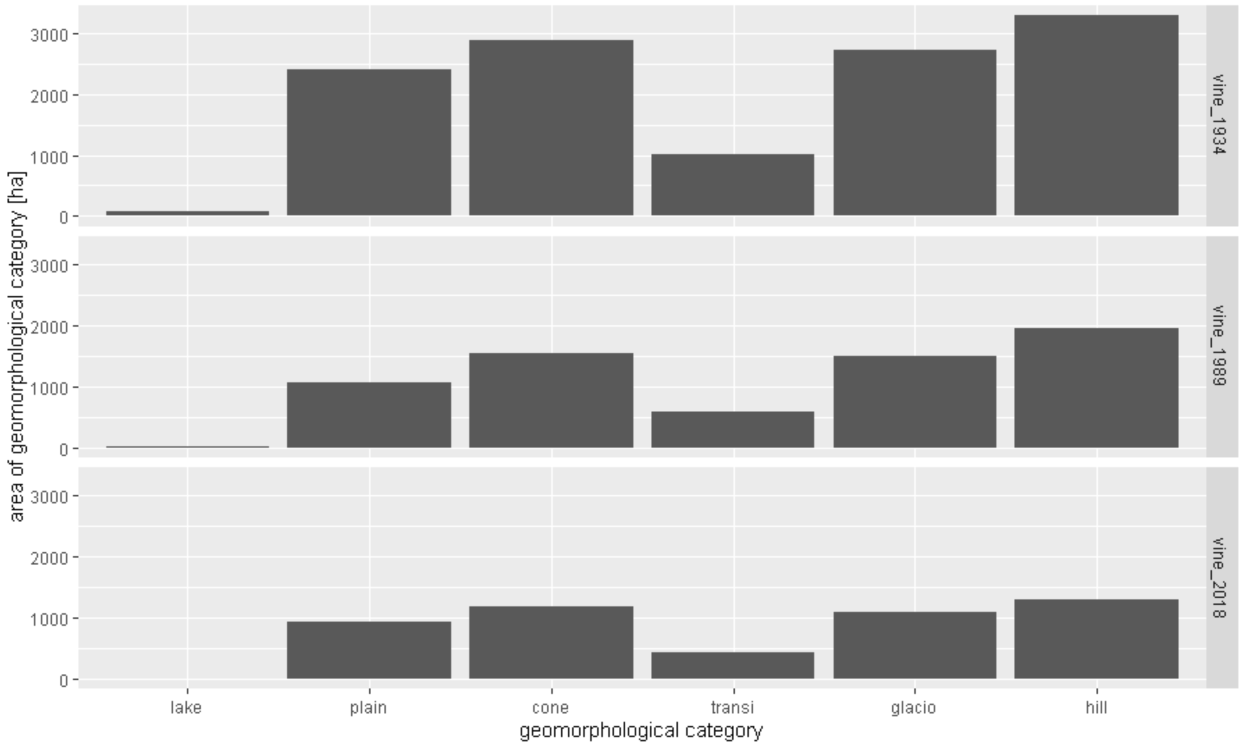

Figure 16 – Distribution of the vineyard cells per time window over geomorphological categories.

Looking at the percentage of each total geomorphological category covered by vineyard cells (Fig. 17) shows that, as the vineyard area decreases, all geomorphological categories are also less covered. Vineyard cells cover a larger area of the debris cones and glacial terraces. The hillside geomorphological category, on the other hand, is the least covered by vineyards, because accessibility and vineyard management are more difficult.

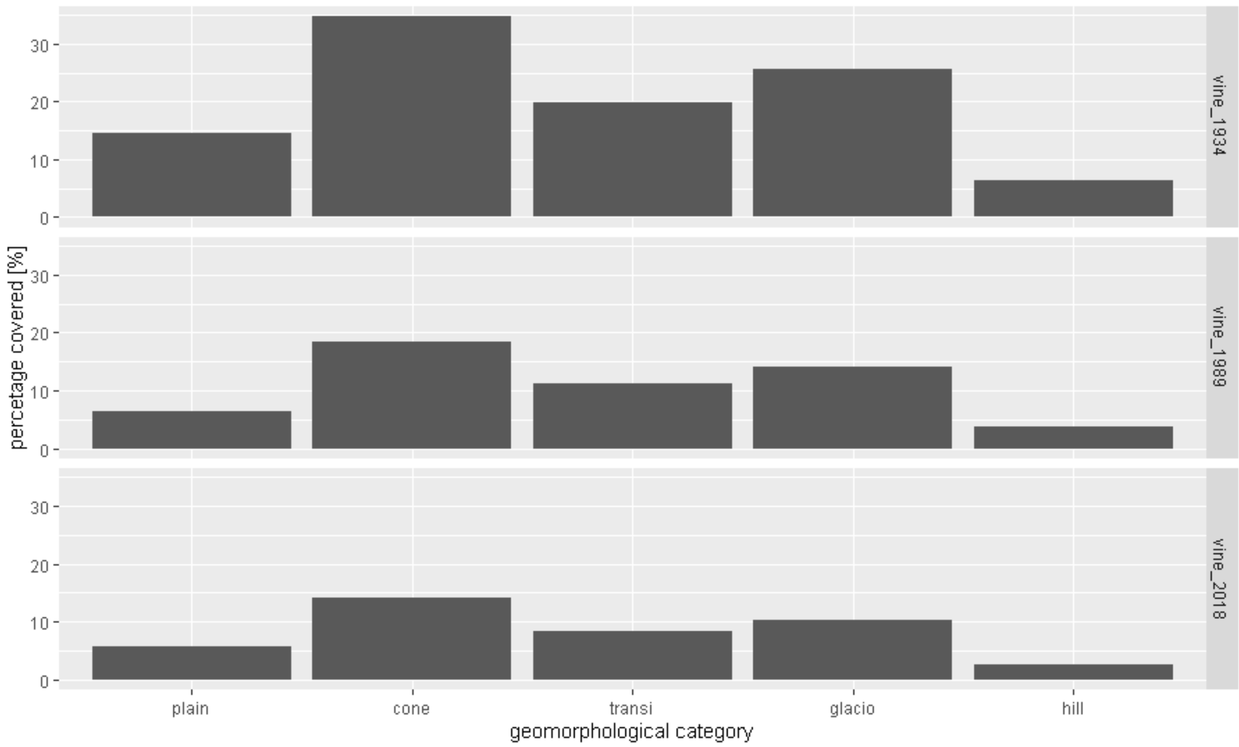

Figure 17 – Evolution of the percentage of the whole geomorphological category covered by vineyard cells.

It seems that the distribution across geomorphological categories has not changed much over time, except that the area represented is less large as the number vineyard cells has decreased. However, the composition of the vineyards has changed across the altitude categories. The first row of Figure 17 shows the distribution of the vineyard area by altitude categories and the changes between time windows (column on the right). The altitude categories are based on the definition of the quantiles. Vineyards are distributed throughout the last century in an altitude range between 190 m (i.e. minimum altitude in the study area) and 915 m. Most of the vineyards (about 45% in each time window) were and still are located at altitudes between 290 m and 400 m. In this altitude range the loss was greatest between the first two time windows, but not between 1989 and 2018 when the vineyards kept more or less equally distributed over the whole altitude range.

The analysis of existing forest area in the vineyard cells with respect to the altitude categories (Fig. 17, second row) shows that the forest area roughly follows the vineyard distribution. Most of the vineyard-related forest area is located in the altitude category 290-400 m. In general, while the area of vineyards decreases over time, the presence of forest area also decreases, with the exception of a temporary increase in forest area between 1934 and 1989 at lower altitudes.

The same phenomenon can be observed when analysing the presence of buildings area within the vineyard cells (Fig. 17, third row). A general decrease in the basal area of buildings (i.e. building footprint area) is observed for altitudes above 290 m, but an increase between 190 m and 290 m.

On the other hand, the number of buildings shows a completely different picture with an increase in all vineyard cells towards 2018 (Fig. 17, fourth row).

Vineyards are distributed over slope values ranging from 0° to 60° with most of the vineyard area located in the categories 5°-15° and 20°-60° in all time windows (Fig. 18, first row). The slope categories are based on the definition of the quantiles. The high slope values (i.e. 60°) can be explained by the fact that some terraced vineyards are distributed in more mountainous areas, where the average slope of the vineyard cell is resulting high, corresponding to an aggregation uncertainty. Vineyard area values also decreased in all slope categories with the greatest loss between 1934 and 1989 in the second slope category.

The forest area within the vineyard cells of the corresponding year decreased with steeper slopes, but increased near the valley floors and glacier terraces, where slopes are gentler.

The values of building area also decreased in all slope categories (Fig. 18, third row), especially for vineyard cells located at slopes above 5°. While the number of buildings has increased on all slopes values.

In general, it can be assumed that the composition of the vineyard cells has not changed over the years, except for the increase in the number of buildings and forest and building area values on gentler slopes.

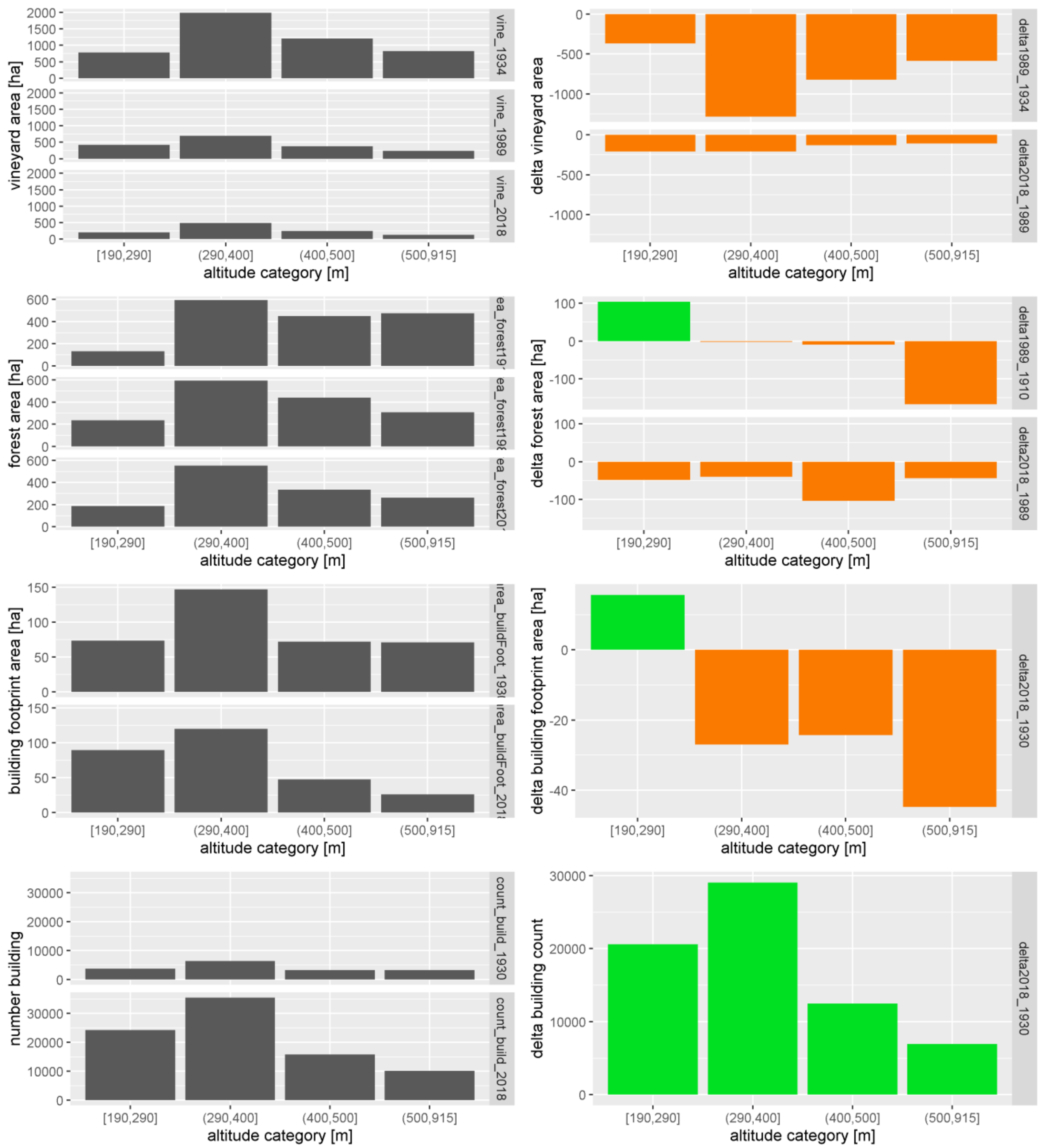

Figure 18 – Distribution (from top left) of vineyard, forest and building footprint area [ha] and building count over altitude categories [m]. Difference of (from top right) vineyard, forest and building area and building count over altitude categories. The values are based on the vineyard cells of the respective year in which the data sets are available. Green bars indicate an increase, while orange ones indicate decrease.

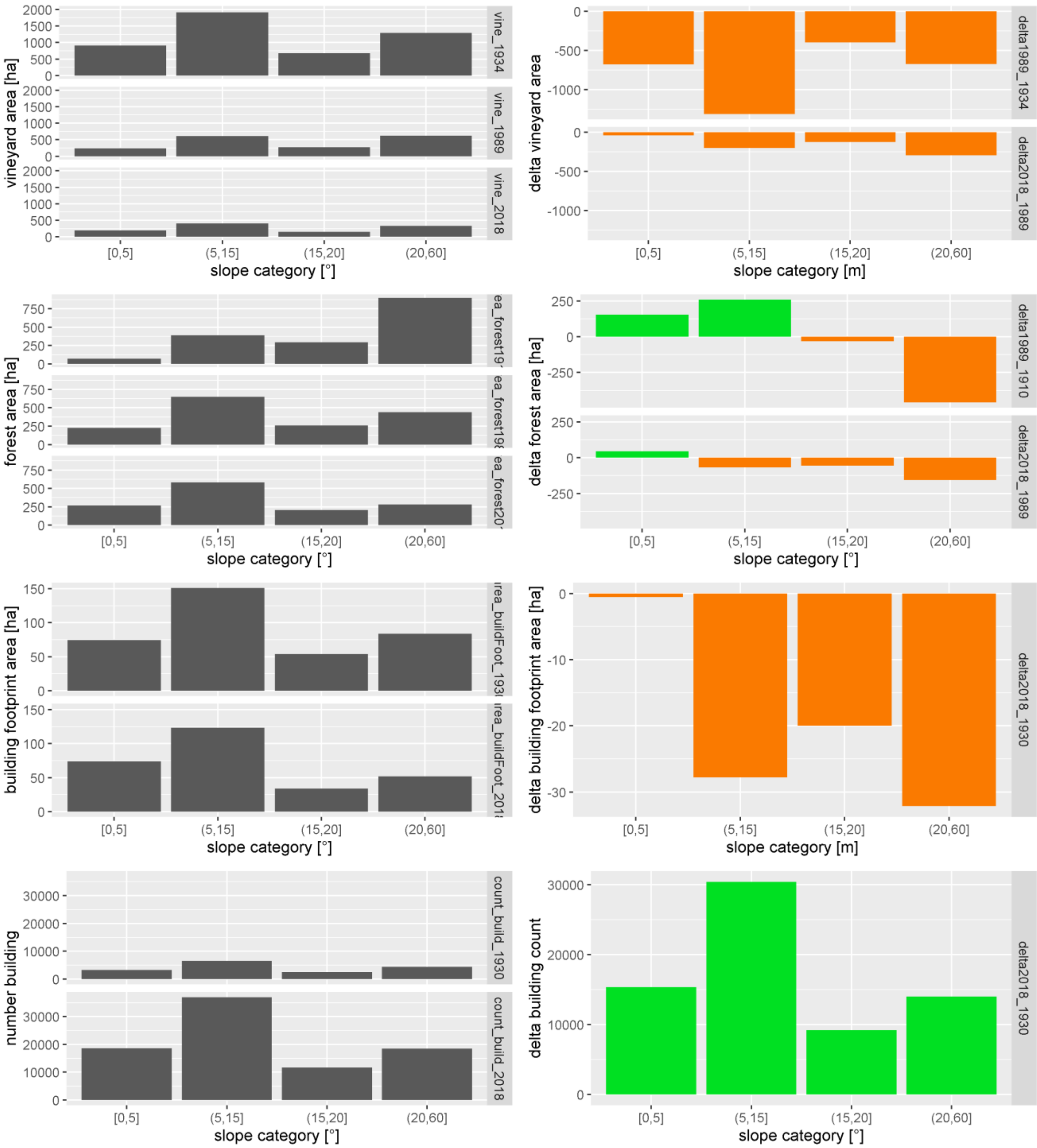

Figure 19 – Distribution (from top left) of vineyard, forest and building footprint area [ha] and building count over slope categories [°]. Difference of (from top right) vineyard, forest and building area and building count over slope categories. The values are based on the vineyard cells of the respective year in which the data sets are available. Green bars indicate an increase, while orange ones indicate decrease.

3.3 Random Forest analysis results

To identify which factors are relevant, I applied the Random Forest machine learning technique to six response variables: vineyard area in 1934, vineyard area in 1989, vineyard area in 2018, change in vineyard area 1934-1989, change in vineyard area 1989-2018 and change in vineyard area 1934-2018.

The RF was performed for each of the six response variables once to select the variables with an importance value greater than 30. In this case, all plausible temporal variables were chosen as explanatory variables. The graphs resulting from this first run are in Appendix 11.2. Then RF was run a second time on the selected explanatory variables, with aim to identify the driving factors

The second run of RF explained the variance of the response variables in a range between 26% and 45% (Tab. 6). The variances of four response variables are explained by a little less than half. The lowest values were achieved by performing RF on the response variables of the difference of vineyard area between the years 1989 and 2018 and vineyard area in 2018. Perhaps, due to an uneven distribution of cells by vineyard area and vineyard area difference, RF mainly analyses the influence of the variables in most cases of the response variables. Indeed, a look at the partial response plots (Appendix 11.3) shows the influence of the explanatory variables in the range of vineyard area values, which are more common, but do not account for the entire variance.

Table 6 – Summary of the explained variance by the second run of Random Forest carried out on selected explanatory variables.

Response variable	Percentage of explained variance [%]
Vineyard area in1934	44.81
Vineyard area in 1989	40.93
Vineyard area in 2018	36.94
Difference in vineyard area 1934-1989	44.55
Difference in vineyard area 1989-2018	26.35
Difference in vineyard area 1934-2018	45.33

The importance plots of the RF applied on the vineyard area in 1934, 1989 and 2018 (Fig. 19) already give an idea of the driving factors. In all time windows, one of the most influential variables is altitude. Moreover, vineyard suitability is also important since 1934, as variables such as slope, insolation and aspect are ranked in Figure 19. However, socio-economic factors are also influential, as population density and the number of employees are also considered. The forest seems to lose its importance over time, while the regional effect (municipalities in 1990 and the section of Federviti) are becoming more influential.

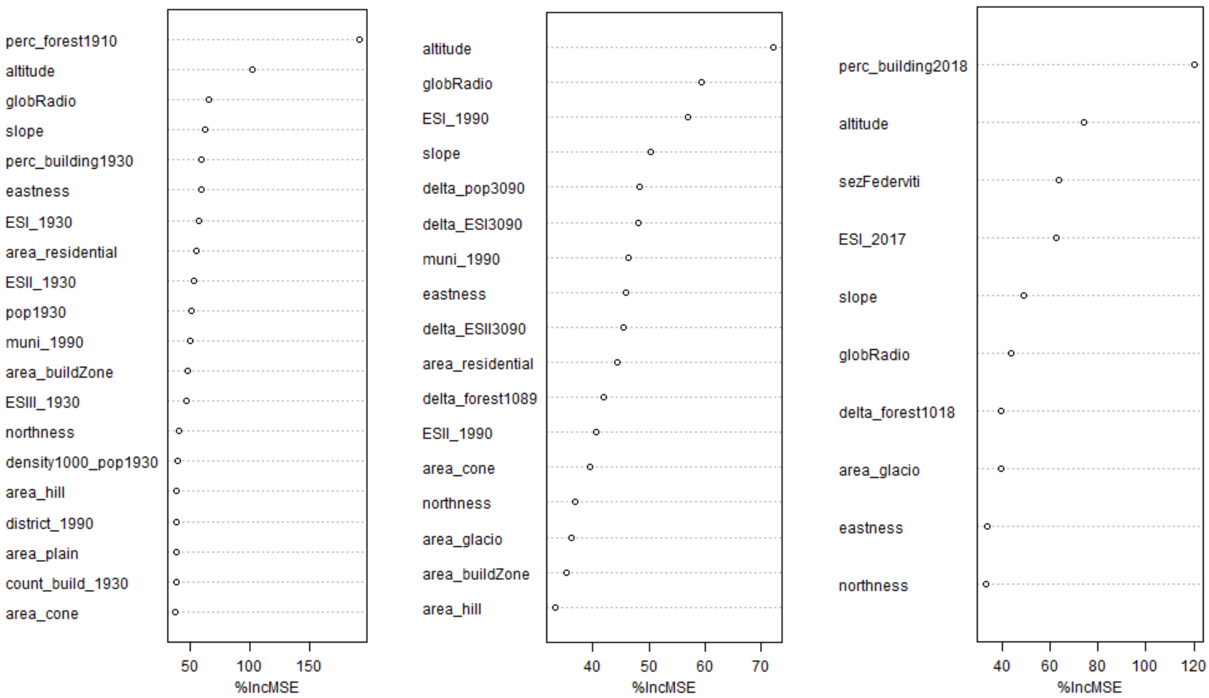

Figure 20 – Importance plot of Random Forest as regression method carried out on vineyard area in 1934 (left), in 1989 (middle) and 2018 (right).

It becomes more interesting to analyse the results of the RF carried out on the variation of the vineyard area between the time windows, as it shows several driving influencing factors, even if the general trend has been a decrease of the area.

The evolution of the vineyard area between 1934 and 1989 is mainly affected by a regional effect represented by the explanatory variable of the Federviti section (Fig. 20). As mentioned in the introduction, in the year 1948 winegrowers organised themselves and founded this federation of winegrowers of the Swiss-Italian region (Panzera, 2017). Federviti is divided into sections, which are a simplification of the district structure (Fig. 21). The high importance of the explanatory variables of the change in forest area and the percentage of forest covering the viticultural cell suggests that forest was a driving factor causing the decrease in vineyard area. In addition, socio-economic factors had some importance, but less than the pressure of building footprints in 1930.

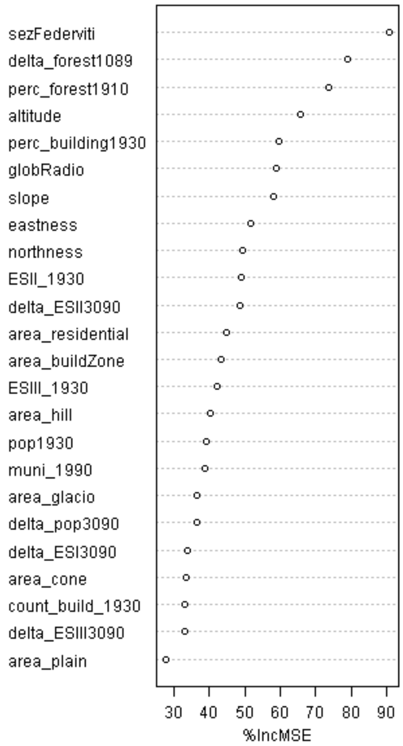

Figure 21 – Importance plot of Random Forest as regression method carried out on vineyard area change between 1934 and 1989.

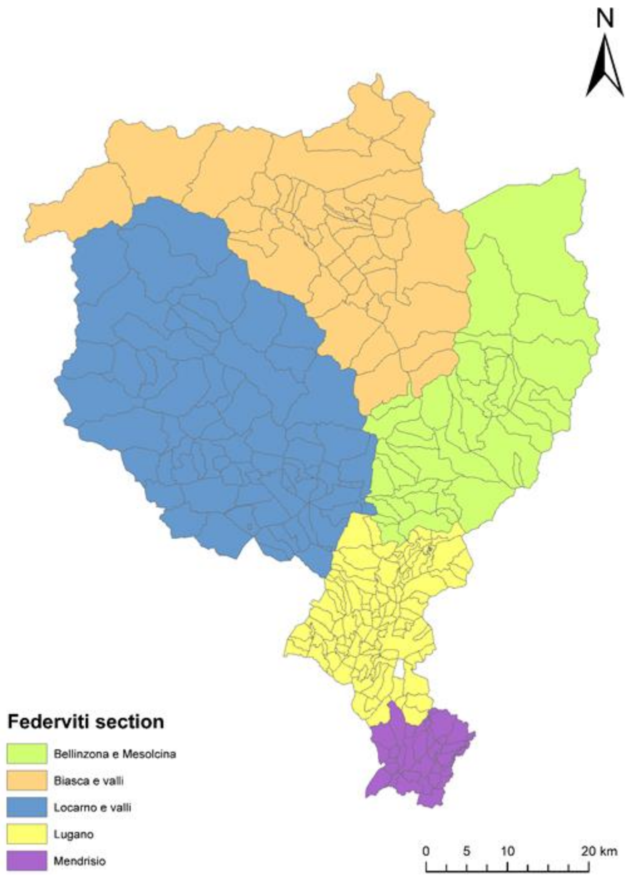

Figure 22 – Municipalities divided into the sections of Federviti.

A more detailed analysis looks of the evolution of vineyards as the coverage of the forest area changes (Fig. 22). The first row shows that the average area of the vineyard cells in 1934 was greater within the cells where the percentage forest cover in 1910 was less. In these cells, the average vineyard area decreased in 2018 while the forest area coverage increased. Furthermore, it can be seen that for a high percentage forest area coverage in 1910 the average area was low and still is, although the forest area in 2018 has decreased.

A look at the evolution of the forest area from 1910 to 2018 in the vineyard cells of the year 1934 (Fig. 23) shows a change in the land cover. Indeed, the number of cells is increasing over time, showing that more vineyard cells from 1934 are now covered by forest area. This may mean that the abandonment and decrease of the vineyards have been driven by forest pressure or that the forest has simply occupied the vacant areas.

The same phenomenon of decreasing average vineyard area within the cells is shown by looking at the percentage of building footprint (Fig. 24). In fact, the cells with the highest average vineyard values in 1934 had a small building footprint coverage compared to the building in 1930. These cells would have a higher percentage of building area in 2018, but the average vineyard area has decreased over time. Cells with a higher average vineyard area have less percentage of buildings in 2018.

Looking at the evolution of the building footprint within the vineyard cells in 1934, it can be seen that in 2018 there are probably fewer cells with a building area of less than 500 m^2 but more cells with higher values. This suggests that settlement development has taken place in the vineyard cells, which is a possible sign of pressure and land use change.

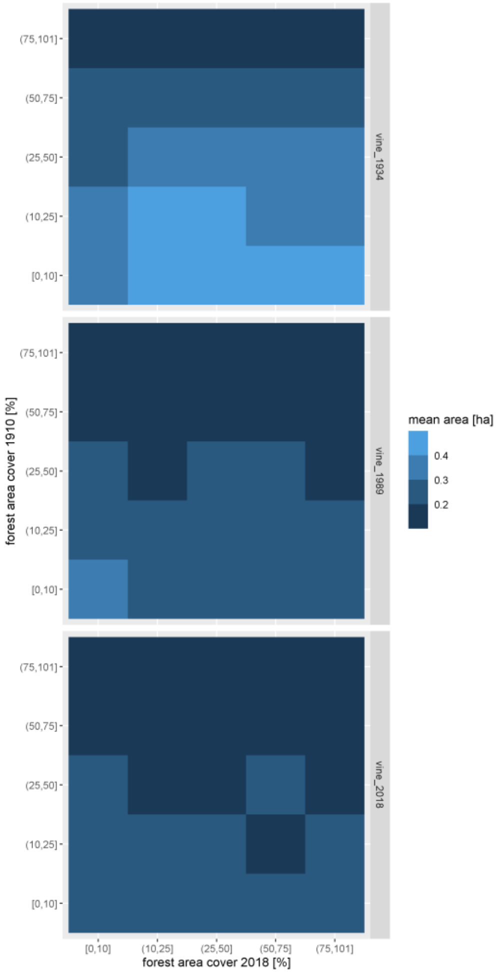

Figure 23 – Change of mean vineyard area [ha] per cell over forest cover percentage categories [%] in 1910 (y-axis) and in 2018 (x-axis).

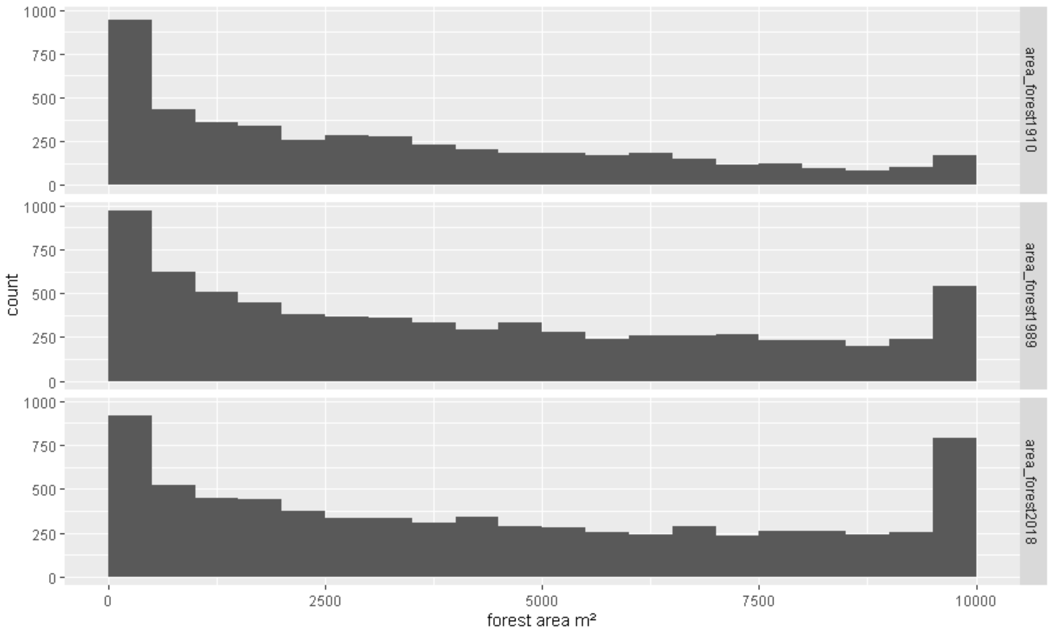

Figure 24 – Distribution of the forest area [m^2] coverage over the years (from top: 1910, 1989 and 2018) inside the vineyard cells in 1934.

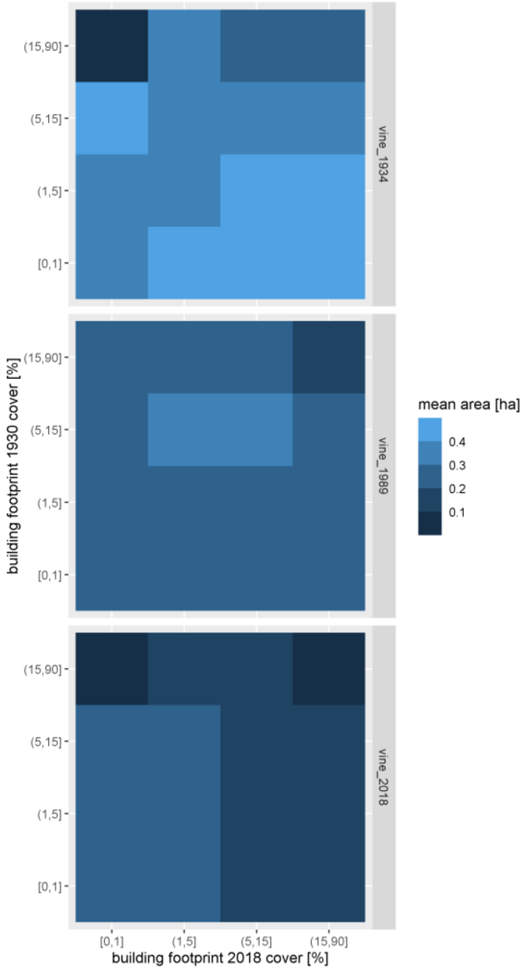

Figure 25 – Change of mean vineyard area [ha] per cell over building footprint percentage categories [%] in 1930 (y-axis) and in 2018 (x-axis).

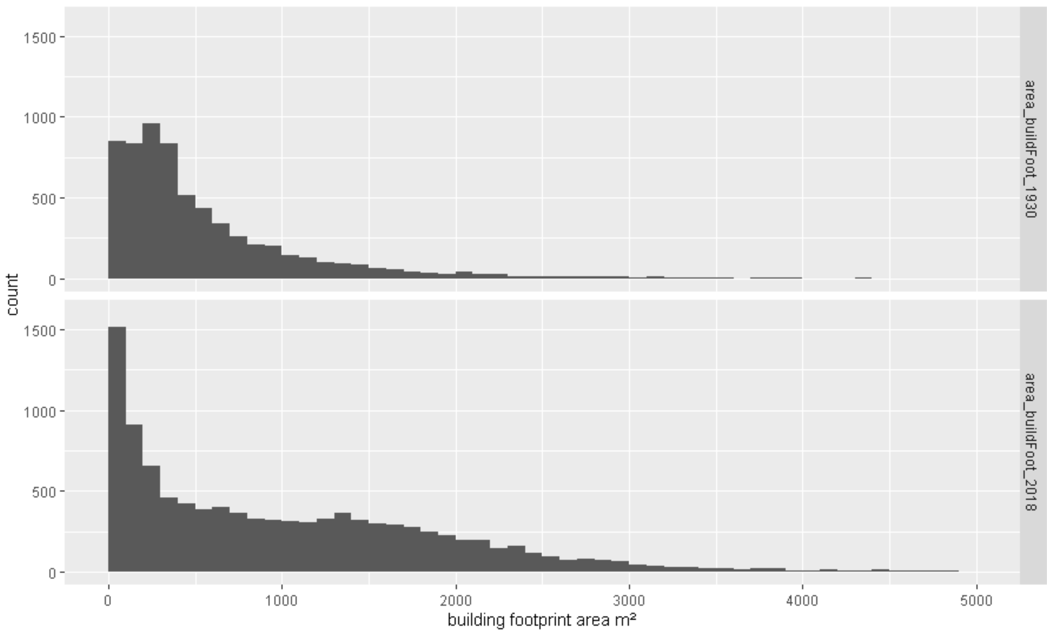

Figure 26 – Distribution of the building footprint area [m²] coverage over the years inside the vineyard cells in 1934.

The RF carried out on the change in wine-growing area from 1989 and 2018 (Fig. 26) shows a similarity and various differences with respect to the evolution between the first two time windows (Fig. 20). The similarity lies in the high importance of the explanatory variables of geomorphological factors (altitude, slope, aspect and insolation), showing that the suitability of the terrain influenced the evolution.

The first difference is the lack of importance of the regional effect with the missing variable of Federviti sections. Although the municipalities in 1990 and aggregated municipalities in 2018 are quite important.

The second difference is the missing land cover factors that influenced the evolution from 1934-1989. In fact, none of these is listed. Perhaps, the missing information of building footprints in 1989 is a reason for the lower strength in explaining the variance (Tab. 6).

The third and last obvious difference is the importance of socio-economic factors. In fact, the evolution of the population and its density, as well as the evolution of the number of employees in the primary and tertiary economic sector, are considered as driving factors of the decrease.

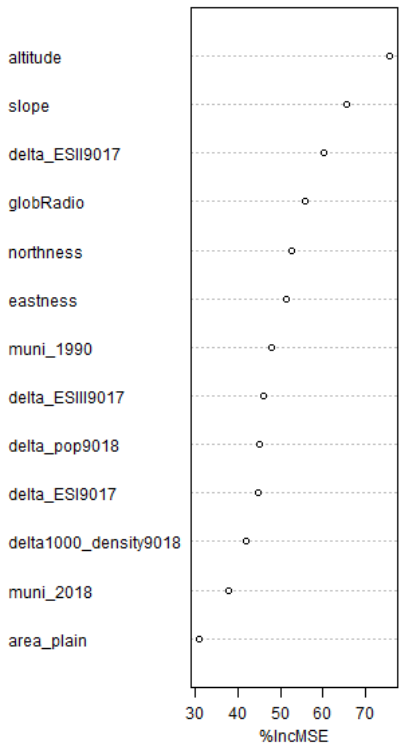

Figure 27 – Importance plot of Random Forest as regression method carried out on vineyard area change between 1989 and 2018.

Looking in more detail at the evolution of the number of employees by economic sector (Fig. 27), two aspects can be analysed. Firstly, the evolution of employees at the district level shows a general decrease of employees in the primary economic sector and an increase of employees in the tertiary economic sector. This indicates the socio-economic transformation of the population in the study area towards a society based more on the service sector. The second aspect highlighted is the difference between the more rural districts (Leventina, Blenio, Moesa, Vallemaggia and Riviera and the more urban districts (Locarno, Bellinzona, Lugano and Mendriso). The latter are characterised by the presence of at least one large city. As can be seen by observing the distribution of vine cells over time (Fig. 10) and the evolution of vineyards (Fig. 15), in the urban district the vineyard area has been greater and the decrease has also been greater.

A closer look at the change in population density and the mean vineyard area per cell (Fig. 28) shows its influence. In general, in 1934, the mean area per vineyard cell was the highest and then decreased. This indicates that as the population density increases, the average vineyard area decreases.

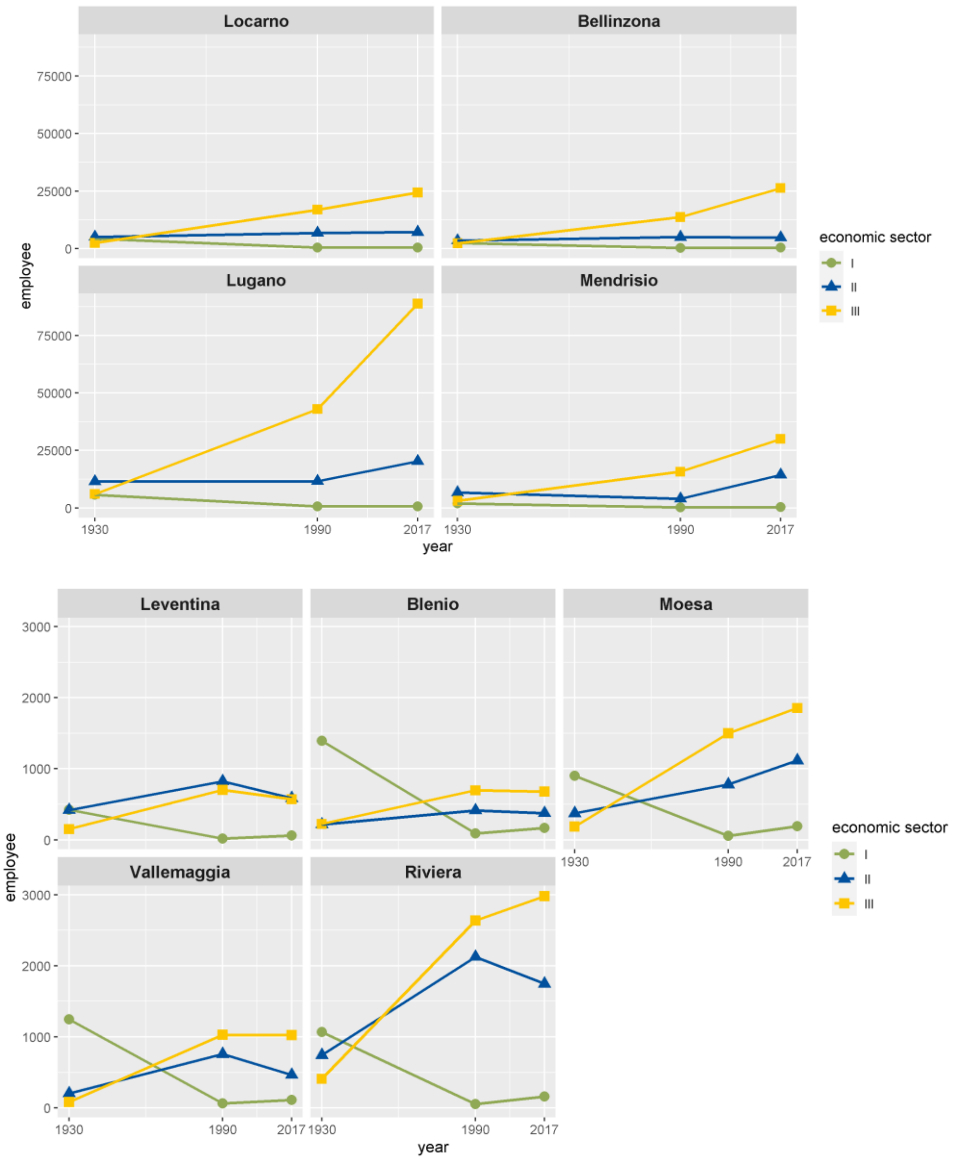

Figure 28 – Evolution over time windows of employees per economic sector per district. The first plot representing the evolution for the more urban districts; the second for the more rural districts without major cities.

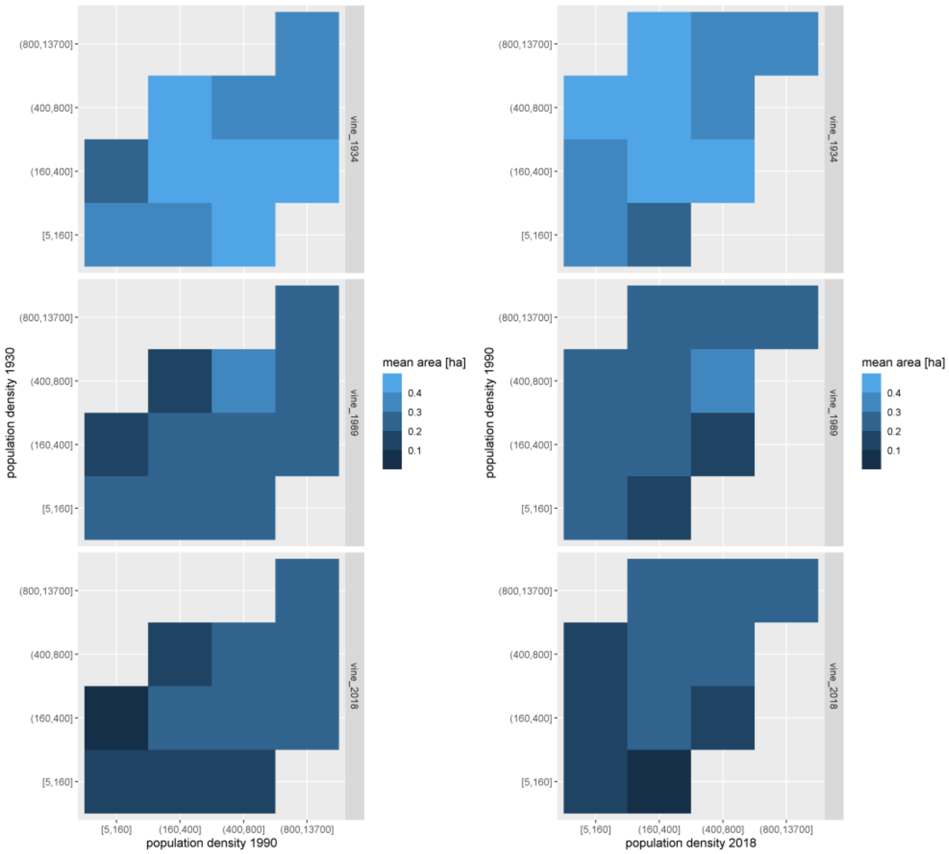

Figure 29 – Change of mean vineyard area [ha] per cell over population density below 1000 m altitude categories [inhabitants/km^2]. Left plot: population density 1930 (y-axis) and 1990 (x-axis). Right plot: population density 1990 (y-axis) and 2018 (x-axis).

The RF importance plot made on the difference in vineyard area between 1934 and 2018 (Fig. 29) is like a synthesis of the RF analysis made on the difference 1934-1989 and 1989-2018. This is because all types of driving factors are listed as important.

Like for the evolution of vineyards in the period 1934-1989, land cover factors (forest area and building footprint) are important, as well as geomorphological categories (altitude, slope, exposure and insolation), which describe suitability for vineyards.

In addition, socio-economic factors (population and employees) are important as drivers as for the vineyard evolution in the period 1989-2018.

As the forest factor is the most important and the regional effect (Federviti section) is important too, they suggest that the general evolution of vineyards between 1934 and 2018 is more dominated by the evolution between the first two time windows (1934-1989).

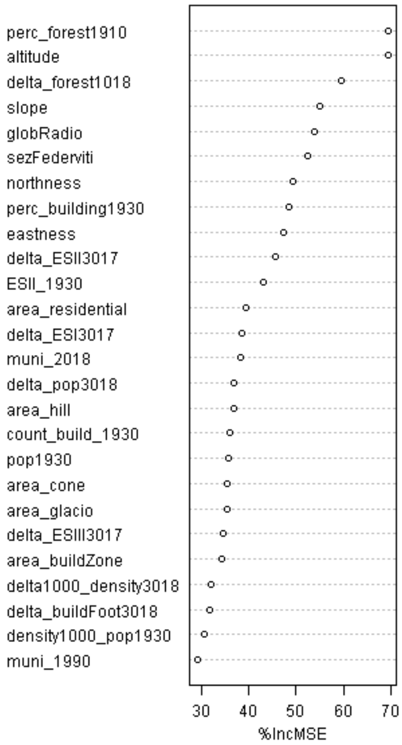

Figure 30 – Importance plot of Random Forest as regression method carried out on vineyard area change between 1934 and 2018.

4 Discussion

4.1 Characterisation of the evolution of vineyards

The distribution of vineyard cells over time confirms the observations made in the literature about the location of the vineyards. These are located near the socio-economic areas of the study area along the major valleys (Krebs & Bertogliati, 2017; Panzera, 2017).

Between 1934 and 1989, where the vineyard area was greater, the decline was also greater. This happened mainly in the districts of Bellinzona, Locarno, Lugano and Mendrisio, where the largest cities in the study area are now located. During the same period, there was also an increase in the vineyard area on the southern coast of Lake Maggiore. Between 1989 and 2018, there was a decrease in vineyard area on the southern coast of Lake Maggiore, while there was a slight increase in the urban districts. It can be observed that the increase is not large enough to compensate the amount of decrease.

The development of the vineyard area in the Canton of Ticino and in the Moesa Region is characterised by a general decrease. In general, the vineyard area has also become smaller, as fewer cells are completely or almost completely covered by vineyards. However, there are spatial and temporal variations in the development. In fact, the evolution is not characterised by a complete decline, as there have been local and temporal increases (Fig. 15), indicating that viticulture was still active in the study and not in complete decline.

The general evolution can be deepened, by looking at higher spatial resolution and higher temporal resolution. For example, by analysing the changes in vineyard surface for specific valleys or by introducing another intermediary time window.

4.2 Characterisation of the vineyard cells composition

The characterisation of the vineyard cell composition shows no important changes in forest and building area over time, except the increasing number of buildings in 2018 within the cells. In general, this gives the idea that the general composition of the vineyard cells has not changed, since with the decrease in the vineyard values, the values of the forest area and the area of the building footprint are also decreasing. Only the increase in the number of buildings and the increase in the area of the footprint of buildings in the lowlands can suggest that they have influenced the evolution of the vineyard area. The analysis of the evolution of land cover factors determining the composition of vineyard cells over categories of altitude and slope does not provide clear ideas on what influenced the vineyard evolution, as the composition within the cell remained practically the same across time windows. So the question remains open as to what occupied the vacant space given by the decline of the vineyards. This question is then answered by the later analysis of the driving factors and by looking at the increasing forest and building land values within the 1934 vineyard cells.

Consideration must be given to the oddity that the number of buildings has increased over time, but not the total building footprint area. This is perhaps due to the fact that the building footprints for 1930 were extracted from the old Siegfried maps (Heitzler & Hurni, 2020), which do not have the same accuracy as the current national maps. For future in-depth analyses, it must be taken into account that the size of the 1930 building footprints must be corrected.
However, the increasing number of buildings may indicate two aspects. First, the relocation of vineyards to lower elevations closer to the socio-economic activity areas in the valley bottoms. Second, the urbanisation of the settlements that include the vineyards. Indeed, when looking at the vineyard area within the construction zones in 2017, one can see that large parts of the vineyard area for each time window are located within the construction zones and residential areas (Tab. 7).

Table 7 – Vineyard area intersecting building zones and residential areas of 2017.

	Total inside cells	Building zones	Residential area
Vineyard area in 1934	4791.288 ha	3444.345 ha	3029.488 ha
Vineyard area in 1989	1733.105 ha	1138.231 ha	999.0461 ha
Vineyard area in 2018	1073.554 ha	516.4039 ha	413.0429 ha

4.3 Identification of the driving factors influencing the evolution of vineyards

The analysis of the driving factors describing vineyard area in the three time windows (1934, 1989 and 2018) and the variation in vineyard area for the period between the time windows (1934-1989, 1989-2018 and 1934-2018), carried out using the Random Forest algorithm, revealed different patterns.
All six response variables were mainly influenced by the suitability of the terrain described by geomorphological factors (i.e. altitude, slope, aspect and solar radiation), among other specific drivers. Since vines are a crop, the suitability of an area is always important. Moreover, it has been noted in the literature that vine cultivation in the Canton of Ticino and in the Moesa Region was mostly a secondary activity and not always grown in the most suitable areas (Panzera, 2017). This fact may indicate that most of the decline is due to the lack of suitability.

The development of vineyards in the period 1934-1989 can be partially described by building footprints and mainly by the forest area and. This may indicate two aspects. First, the expansion of forest area causes pressure on vineyard management, due to ungulate damage and the difficulty of managing the vineyard-forest boundary (Maddalena, 2020b). Secondly, forest has taken over the free space created by the decreasing vineyard area (Fig. 24). Indeed, this answers the open question after analysing the vineyard composition: forest and buildings took the place of vineyards as land cover (Fig. 24 & Fig. 26). Another important driving factor affecting development is the Federviti section. This shows the regional effect that may have influenced viticulture through organisation by such federation.

During the period 1989-2018, the more important driving factors were the socio-economic factors, such as the density and variation of the population and the variation in the number of employees per economic sector. This shows the final process of social transformation of society in the Canton of Ticino and the Moesa Region after the Second World War. This transformation led to a society based on the tertiary sector of the economy, the service sector, and no longer relying solely on agriculture and industry.

The partial response plots (Appendix 11.3) and the percentages of variance explained (Tab. 6) show that Random Forest explains the most frequent cases. Perhaps by applying the RF method on the one hand to the decrease in vineyard area and on the other hand, to the increase in vineyard area, it would be possible to get a better idea of the driving factors affecting these different phenomena. To get a better idea of the effective importance of the driving factors, it would also be necessary to evaluate their actual effect on the response variable. Finally, a validation of the RF results would also give more certainty. Although this simple application of the RF already provided interesting aspects about the development of the vineyards.

5 Conclusions

This Master's thesis characterise the evolution of vineyard area and its driving factors in the Canton of Ticino and in the Moesa Region. It concludes that although the general picture is characterised by the decrease of vineyard area, the evolution is more complex, as there are spatial and temporal variations. In fact, there have been local and temporary increases in vineyard area, showing that the viticulture can still be active in the study area.

Over time, the composition of vineyard cells remained fairly constant, although the number of buildings increased. This indicates the expansion and pressure of settlements and the shift of vineyards toward lower altitudes.

Moreover, the evolution of vineyards was not always driven by the same factors. Between the 1930s and the 1980s, forest was an important factor, due to its advance pressure and substitution as land cover class. Between the 1980s and the 2010s, the vineyard evolution was mainly driven by socio-economic factors, such as population variation and density and variation in the number of employees per economic sector. However, the suitability of the territory, described by geomorphological factors (i.e. altitude, slope, aspect and insolation), was an important driving factor for both periods.

This works represents a first step for future researches on the evolution of vineyard area and provides a basis that can be further analysed. For example, the local and temporal variations of the vineyard evolution can be analysed more in more detail in future in-depth studies, by looking at specific municipality or even at specific vineyards.

The different attributes collected as possible driving factors are an interesting basis to build on. In fact, there is still the possibility to expand the final data set by adding other possible driving factors.

Moreover, the statistical modelling process can be improved by trying other modelling techniques and looking more closely at the effects of each driving factor.

Future studies can also consider this Master's thesis to look at possible future vineyard evolution. Landscape modelling can be used to develop possible future scenarios by also investigating other driving factors. In particular, new studies could deepen the role of the different actors in viticulture in the Canton of Ticino and the Moesa region. As various amateur winegrowers manage also vineyards, the role of these types of actors could be important, because it is often individuals who decide to abandon vineyards. This kind of decision can be driven by different reasons, such as lack of interest of new generations, difficulties in managing vineyards and pressure from building areas. Current political decisions about the future will also influence the decision of the individual vineyard owner, especially in view of the wine market crisis.

This Master's thesis falls into the category of research on land use and cover changes affecting the landscape. As vineyards are an element of the landscape of the Canton of Ticino and the Moesa Region that plays an economic, environmental and cultural role, the decline of the vineyard area not only affects the landscape aesthetics. By understanding the driving factors in the past, it is possible to have a better knowledge of the current situation. This knowledge can help to develop medium- to long-term strategies aimed at landscape sustainability.

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Figure 42	Partial response plots of the five most important variables (except text attribute sezFederviti) according to Random Forest carried out on vineyard area change between 1934 and 2018.

9 List of equation

10 Data sources of driving factors

10.1 Geomorphological factors

10.1.1 Altitude

- Bundesamt für Landestopografie (swisstopo), 2018, *swissALTI3D_2M_LV03_LN02_2018* [Raster data set]. Available under: https://shop.swisstopo.admin.ch/de/products/height_models/alti3D [Last access: 7.12.2020]

10.1.2 Slope

- Based on aggregated altitude

10.1.3 Aspect (northness, eastness)

- Based on aggregated altitude

10.1.4 Insolation

- Based on aggregated altitude

10.1.5 Geomorphological category

- Based on slope

10.2 Land cover factors

10.2.1 Forest

- Bundesamt für Landestopografie (swisstopo), 2020, *Topografisches Landschaftsmodell swissTLM3D – TLM_BODENBEDECKUNG – Wald* [Vector data set]. Available under: https://shop.swisstopo.admin.ch/de/products/landscape/tlm3D [Last access: 8.12.2020]
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10.2.2 Building zone

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10.2.3 Building footprint

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10.2.4 Land cover statistic

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10.3 Socio-economic factors

10.3.1 Municipality boundaries

- Bundesamt für Landestopografie (swisstopo), 2020, *swissBOUNDARIES3D Gemeindegrenzen* [Vector data set]. Available under: data.geo.admin.ch/ch.swisstopo.swissboundaries3d-gemeinde-flaeche.fill/data.zip [Last access: 10.12.2020]

10.3.2 Population (density)

- Bundesamt für Statistik (BFS), 2010, *Evolution de la population selon les niveaux géographiques institutionnels, 1850-2000* [Data set]. Available under: https://www.pxweb.bfs.admin.ch/pxweb/fr/px-x-4004000000_101/-/px-x-4004000000_101.px [Last access: 8.12.2020]

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10.3.3 Employees by economic sector

- Bundesamt für Statistik (BFS), 1934, *Eidgenössische Volkszählung. 1. Dezember 1930 - Band 16: Kanton Graubünden* [PDF]. Available under: https://www.bfs.admin.ch(bfs/de/home/dienstleistungen/historische-daten/publikationen.assetdetail.345900.html [Last access: 8.12.2020]
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11 Appendix

11.1 List of all attributes calculated for each vineyard cell size 100 m

Table 8 – Attribute table description of the final vineyard cells data set.

Column name	**Description**
NUM	Cell identification number
cell_peri	Perimeter of the cell [m]
cell_area	Area of the cell [m^2]
vine_1934	Vineyard area in 1934 intersecting cell [m^2]
vine_1989	Vineyard area in 1989 intersecting cell [m^2]
vine_2018	Vineyard area in 2018 intersecting cell [m^2]
perc_vine_1934	Percentage of the cell covered by vineyard area in 1934 [%]
perc_vine_1989	Percentage of the cell covered by vineyard area in 1989 [%]
perc_vine_2018	Percentage of the cell covered by vineyard area in 2018 [%]
delta_vine_t1	Difference of vineyard area between 1934-1989 within the cell [m^2]
delta_vine_t2	Difference of vineyard area between 1989-2018 within the cell [m^2]
delta_vine_t3	Difference of vineyard area between 1934-2018 within the cell [m^2]
Geomorphological factors	
altitude	Altitude obtained from the digital elevation model aggregate at a resolution of 100 m (DEM 100 m) at the midpoint of the respective cell [m]
alti_min	Minimum altitude obtained from the digital elevation model aggregated to a resolution of 100 m (DEM 100 m) within a radius of 1.5 km around the cell [m]
alti_max	Maximum altitude obtained from the digital elevation model aggregated to a resolution of 100 m (DEM 100 m) within a radius of 1.5 km around the cell [m]

D_altiMin	Difference between minimum altitude obtained from the digital elevation model aggregated to a resolution of 100 m (DEM 100 m) within a radius of 1.5 km around the cell [m] and altitude obtained from the digital elevation model aggregate at a resolution of 100 m (DEM 100 m) at the midpoint of the respective cell [m]
D_altiMax	Difference between maximum altitude obtained from the digital elevation model aggregated to a resolution of 100 m (DEM 100 m) within a radius of 1.5 km around the cell [m] and altitude obtained from the digital elevation model aggregate at a resolution of 100 m (DEM 100 m) at the midpoint of the respective cell [m]
slope	Slope derived from the maximum altitude gradient based on the DEM 100 m [°]
aspect	Cell exposure: north = 0°; east = 90°; south = 180°; west = 270° [°]
northness	Degree of exposure of the cell to the east: south = -1; zenith = 0; north = 1 [-1; 1]
eastness	Degree of exposure of the cell to the east: west = -1; zenith = 0; east = 1 [-1; 1]
globRadio	Average value of the annual global insolation at the midpoint of the respective cell based on DEM 10 m [WH/m^2]
dirRadio	Average value of the annual direct insolation at the midpoint of the respective cell based on DEM 10 m [WH/m^2]
difRadio	Average value of the annual diffuse insolation at the midpoint of the respective cell based on DEM 10 m [WH/m^2]
area_lake	Lake area intersecting cell based on the geomorphological categories raster at resolution 10 m [m^2]
area_plain	Plain area within the cell obtained from the raster of geomorphological categories at 10 m resolution [m^2]
area_cone	Debris cone area within the cell obtained from the raster of geomorphological categories at 10 m resolution [m^2]
area_transi	Transition area within the cell obtained from the raster of geomorphological categories at 10 m resolution [m^2]

area_glacio	Glacier terrace area within the cell obtained from the raster of geomorphological categories at 10 m resolution [m^2]
area_hill	Hillside area within the cell obtained from the raster of geomorphological categories at 10 m resolution [m^2]
Land cover factors	
area_forest1910	Forest area in 1910 intersecting cell [m^2]
area_forest1989	Forest area in 1989 intersecting cell [m^2]
area_forest2018	Forest area in 2018 intersecting cell [m^2]
perc_forest1910	Percentage of the cell covered by forest area in 1910 [%]
perc_forest1989	Percentage of the cell covered by forest area in 1989 [%]
perc_forest2018	Percentage of the cell covered by forest area in 2018 [%]
delta_fores1089	Difference of forest area between 1910-1989 within the cell [m^2]
delta_forest8918	Difference of forest area between 1989-2018 within the cell [m^2]
delta_forest1018	Difference of forest area between 1934-2018 within the cell [m^2]
area_buildFoot_1930	Building footprints area in 1930 intersecting cell [m^2]
area_buildFoot_2018	Building footprints area in 2018 intersecting cell [m^2]
perc_building1930	Percentage of the cell covered by building footprint area in 1930 [%]
perc_building2018	Percentage of the cell covered by building footprint area in 2018 [%]
delta_buildFoot3018	Difference of building footprint area between 1930-2018 within the cell [m^2]
count_build_1930	Number of buildings in 1930 intersecting cell
count_build_2018	Number of buildings in 2018 intersecting cell
mean_area_buildFoot_1930	Average building footprint area in 1930 within cell obtained by dividing building footprint area by number of buildings intersecting the cell [m^2]
mean_area_buildFoot_2018	Average building footprint area in 2018 within cell obtained by dividing building footprint area by number of buildings intersecting the cell [m^2]
area_buildZone	Building zone area in 2017 intersecting cell [m^2]
area_residential	Residential zone area in 2017 intersecting cell [m^2]
area_economic	Economic activity zone area intersecting cell [m^2]
Municipal affiliation	

canton	Canton of respective cell
bfs_1990	Federal Statistical Office's identification number of the municipality of respective cell in 1990, before aggregations
muni_1990	Municipality of respective cell in 1990, before aggregations
area_muni1990	Municipal area in 1990, before aggregations [m^2]
peri_muni1990	Municipal perimeter in 1990, before aggregations [m]
muni90_area1000	Municipal area below 1000 m of altitude in 1990, before aggregations [m^2]
districtNum_1990	Federal Statistical Office's identification number of the district of respective cell in 1990, before aggregations
district_1990	District of respective cell in 1990, before aggregations
muni_2018	Municipality of respective cell in 2018, after aggregations
bfs_2018	Federal Statistical Office's identification number of the municipality of respective cell in 2018, after aggregations
area_muni2018	Municipal area in 2018, before aggregations [m^2]
district_2018	District of respective cell in 2018, after aggregations
sezFederviti	Federviti section of the respective cell
Socio-economic factors	
pop1930	Number of inhabitants in 1930 in the municipality in 1990 where the cell is located
pop1990	Number of inhabitants in 1990 in the municipality in 1990 where the cell is located
pop2018	Number of inhabitants in 2018 in the municipality in 1990 where the cell is located
delta_pop3090	Difference of number of inhabitants between 1930-1990 in the municipality in 1990 where the cell is located
delta_pop9018	Difference of number of inhabitants between 1990-2018 in the municipality in 1990 where the cell is located
delta_pop3018	Difference of number of inhabitants between 1930-2018 in the municipality in 1990 where the cell is located
density_pop1930	Number of inhabitants in 1930 per square kilometre in the municipality in 1990 where the cell is located [inhabitants/km^2]
density_pop1990	Number of inhabitants in 1990 per square kilometre in the municipality in 1990 where the cell is located [inhabitants/km^2]

density_pop2018	Number of inhabitants in 2018 per square kilometre in the municipality in 1990 where the cell is located [inhabitants/km^2]
density1000_pop1930	Number of inhabitants in 1930 per square kilometre in the municipal area below 1000 m altitude in 1990 where the cell is located [inhabitants/km2]
density1000_pop1990	Number of inhabitants in 1990 per square kilometre in the municipal area below 1000 m altitude in 1990 where the cell is located [inhabitants/km2]
density1000_pop2018	Number of inhabitants in 2018 per square kilometre in the municipal area below 1000 m altitude in 1990 where the cell is located [inhabitants/km2]
delta1000_density3090	Difference of number of inhabitants between 1930-1990 per square kilometre in the municipal area below 1000 m altitude in 1990 where the cell is located [inhabitants/km^2]
delta1000_density9018	Difference of number of inhabitants between 1990-2018 per square kilometre in the municipal area below 1000 m altitude in 1990 where the cell is located [inhabitants/km^2]
delta1000_density3018	Difference of number of inhabitants between 1930-2018 per square kilometre in the municipal area below 1000 m altitude in 1990 where the cell is located [inhabitants/km^2]
ESI_1930	Number of employees in the primary economic sector in 1930 in the municipality in 1990 where the cell is located
ESII_1930	Number of employees in the secondary economic sector in 1930 in the municipality in 1990 where the cell is located
ESIII_1930	Number of employees in the tertiary economic sector in 1930 in the municipality in 1990 where the cell is located
ESI_1990	Number of employees in the primary economic sector in 1990 in the municipality in 1990 where the cell is located
ESII_1990	Number of employees in the secondary economic sector in 1990 in the municipality in 1990 where the cell is located
ESIII_1990	Number of employees in the tertiary economic sector in 1990 in the municipality in 1990 where the cell is located
ESI_2017	Number of employees in the primary economic sector in 2017 in the municipality in 1990 where the cell is located

ESII_2017	Number of employees in the secondary economic sector in 2017 in the municipality in 1990 where the cell is located
ESIII_2017	Number of employees in the tertiary economic sector in 2017 in the municipality in 1990 where the cell is located
delta_ESI3090	Difference of number of employees in the primary economic sector between 1930-1990 in the municipality in 1990 where the cell is located
delta_ESI9017	Difference of number of employees in the primary economic sector between 1990-2017 in the municipality in 1990 where the cell is located
delta_ESI3017	Difference of number of employees in the primary economic sector between 1930-2017 in the municipality in 1990 where the cell is located
delta_ESII3090	Difference of number of employees in the secondary economic sector between 1930-1990 in the municipality in 1990 where the cell is located
delta_ESII9017	Difference of number of employees in the secondary economic sector between 1990-2017 in the municipality in 1990 where the cell is located
delta_ESII3017	Difference of number of employees in the secondary economic sector between 1930-2017 in the municipality in 1990 where the cell is located
delta_ESIII3090	Difference of number of employees in the tertiary economic sector between 1930-1990 in the municipality in 1990 where the cell is located
delta_ESIII9017	Difference of number of employees in the tertiary economic sector between 1990-2017 in the municipality in 1990 where the cell is located
delta_ESIII3017	Difference of number of employees in the tertiary economic sector between 1930-2017 in the municipality in 1990 where the cell is located

11.2 Random Forest importance plots of the variable selection

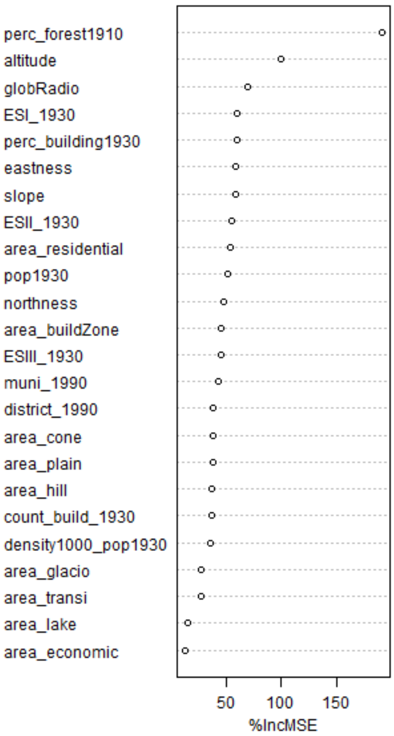

Figure 31 – Importance plot of Random Forest as variable selection method carried out on vineyard area in 1934.

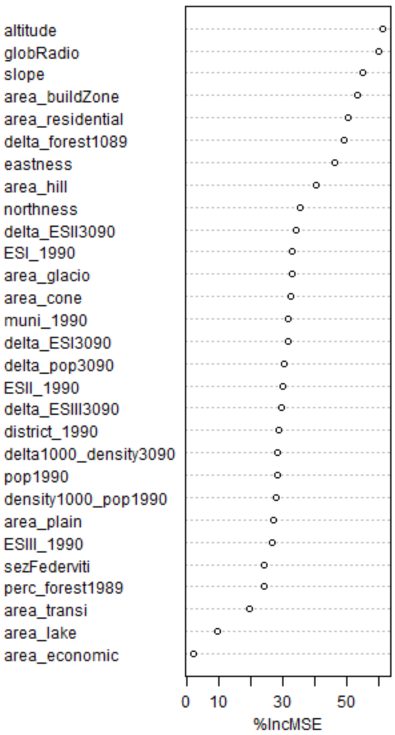

Figure 32 – Importance plot of Random Forest as variable selection method carried out on vineyard area in 1989.

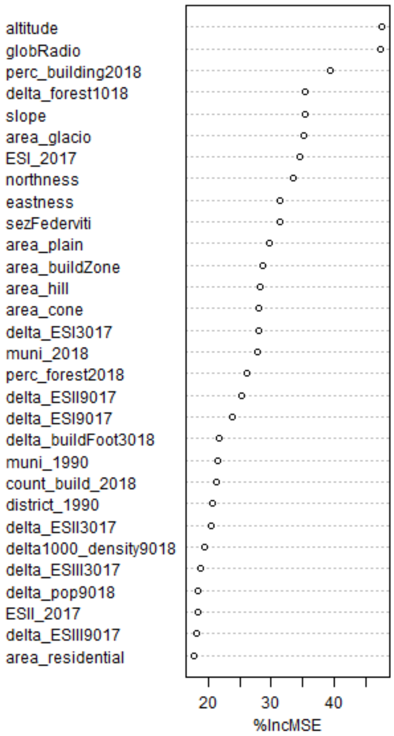

Figure 33 – Importance plot of Random Forest as variable selection method carried out on vineyard area in 2018.

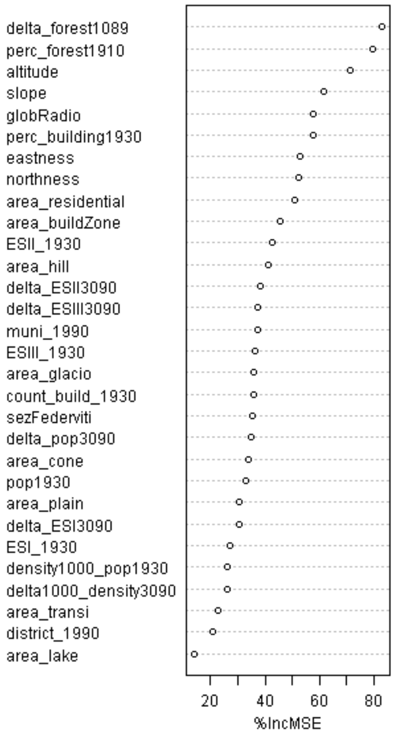

Figure 34 – Importance plot of Random Forest as variable selection method carried out on vineyard area change between 1934 and 1989.

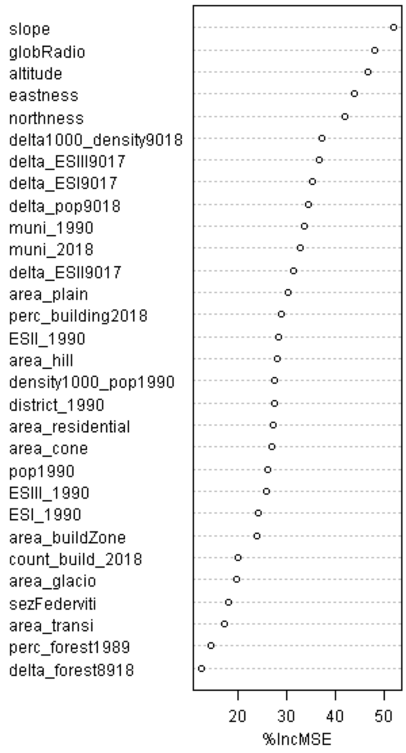

Figure 35 – Importance plot of Random Forest as variable selection method carried out on vineyard area change between 1989 and 2018.

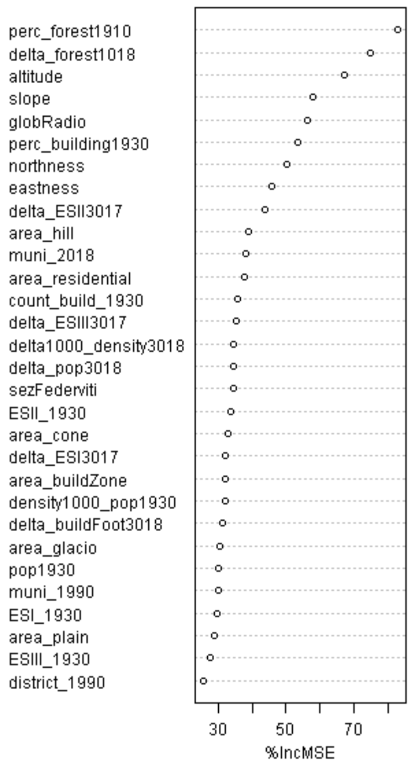

Figure 36 – Importance plot of Random Forest as variable selection method carried out on vineyard area change between 1934 and2018.

11.3 Partial response plots of the Random Forest selected variables

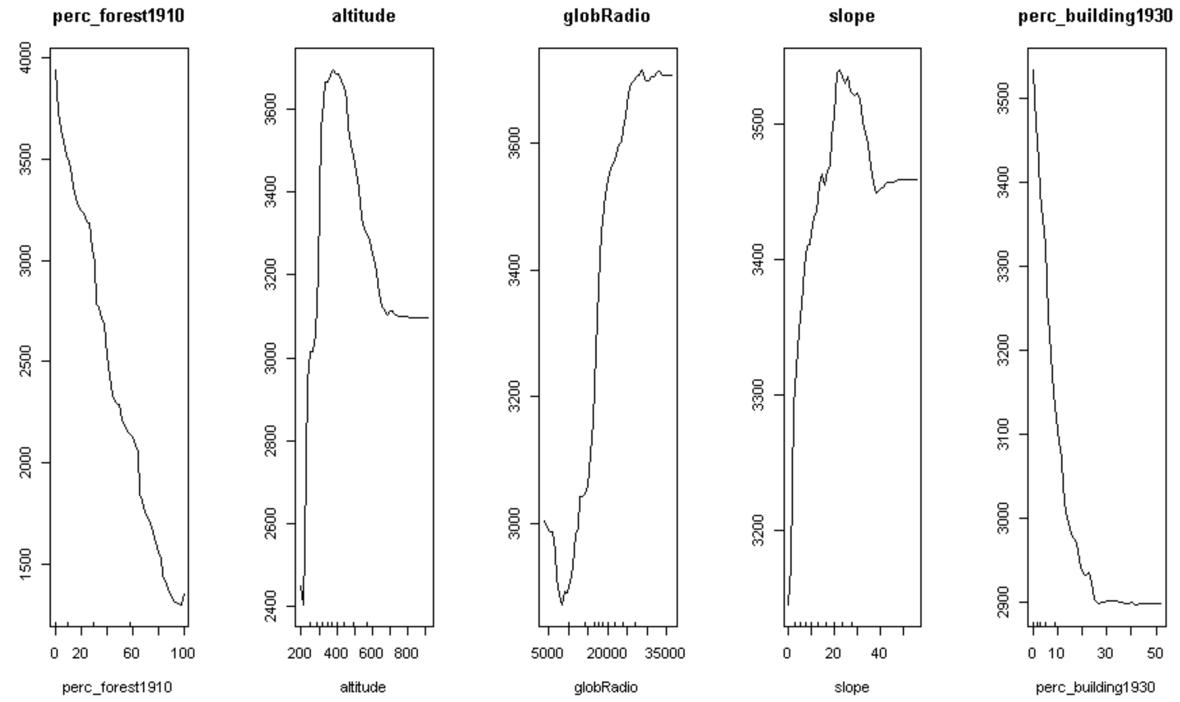

Figure 37 – Partial response plots of the five most important variables according to Random Forest carried out on vineyard area in 1934.

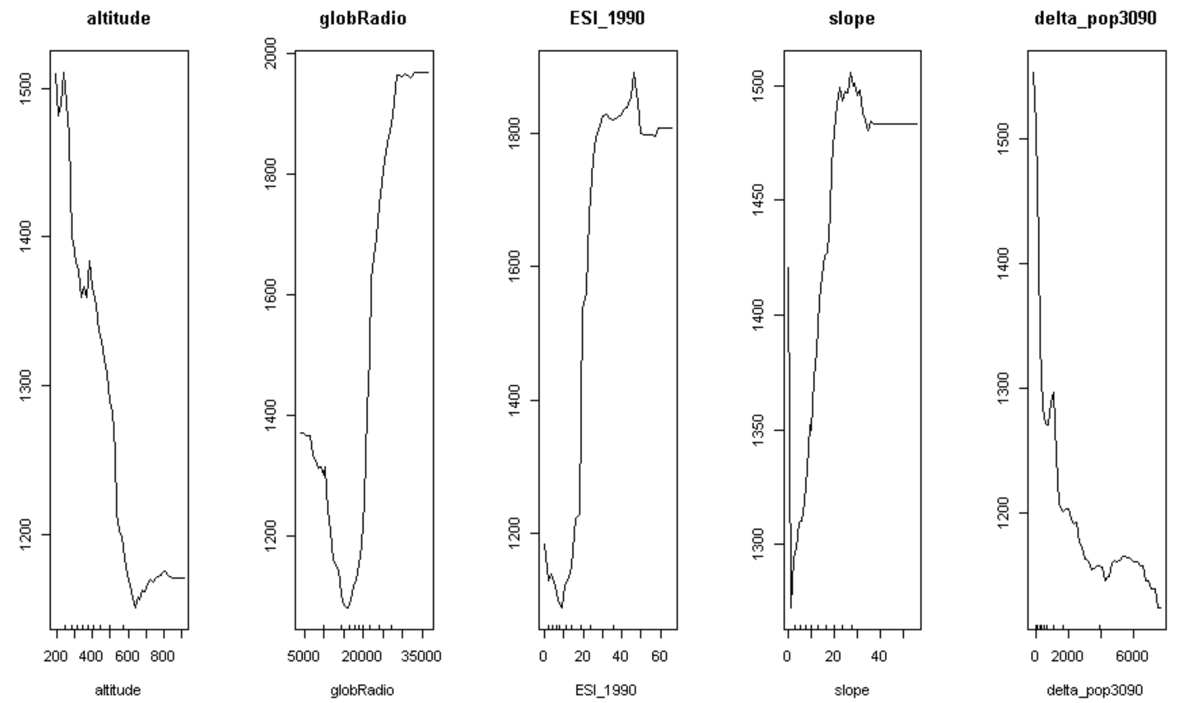

Figure 38 – Partial response plots of the five most important variables according to Random Forest carried out on vineyard area in 1989.

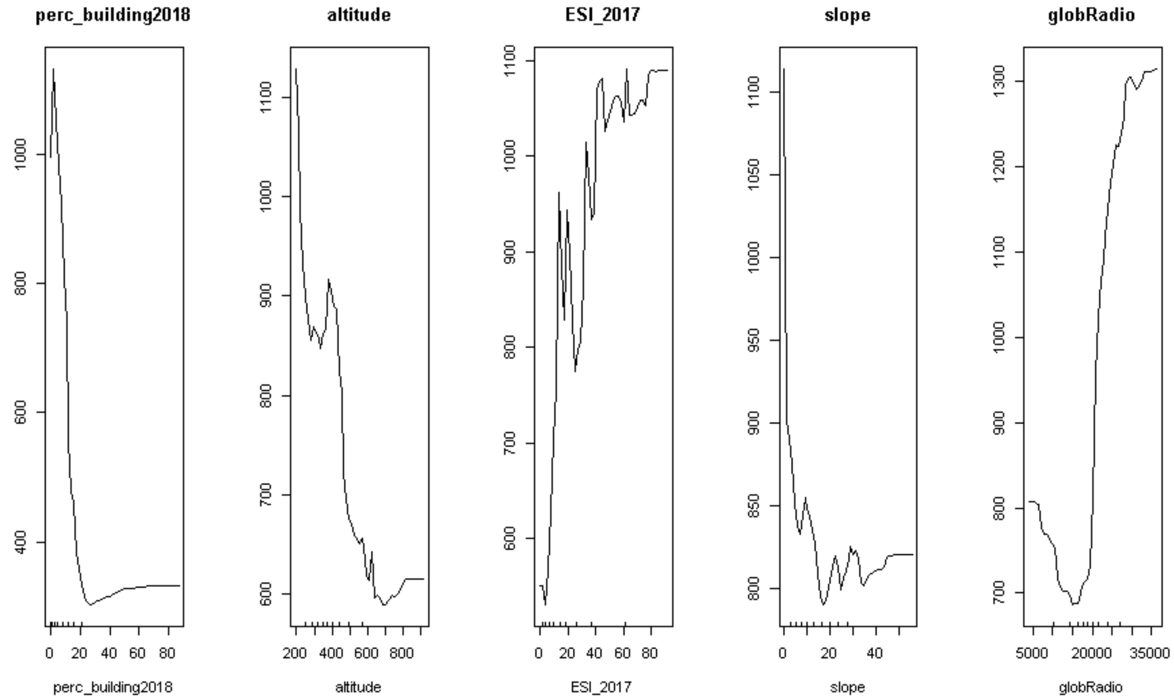

Figure 39 – Partial response plots of the five most important variables (except text attribute sezFederviti) according to Random Forest carried out on vineyard area in 2018.

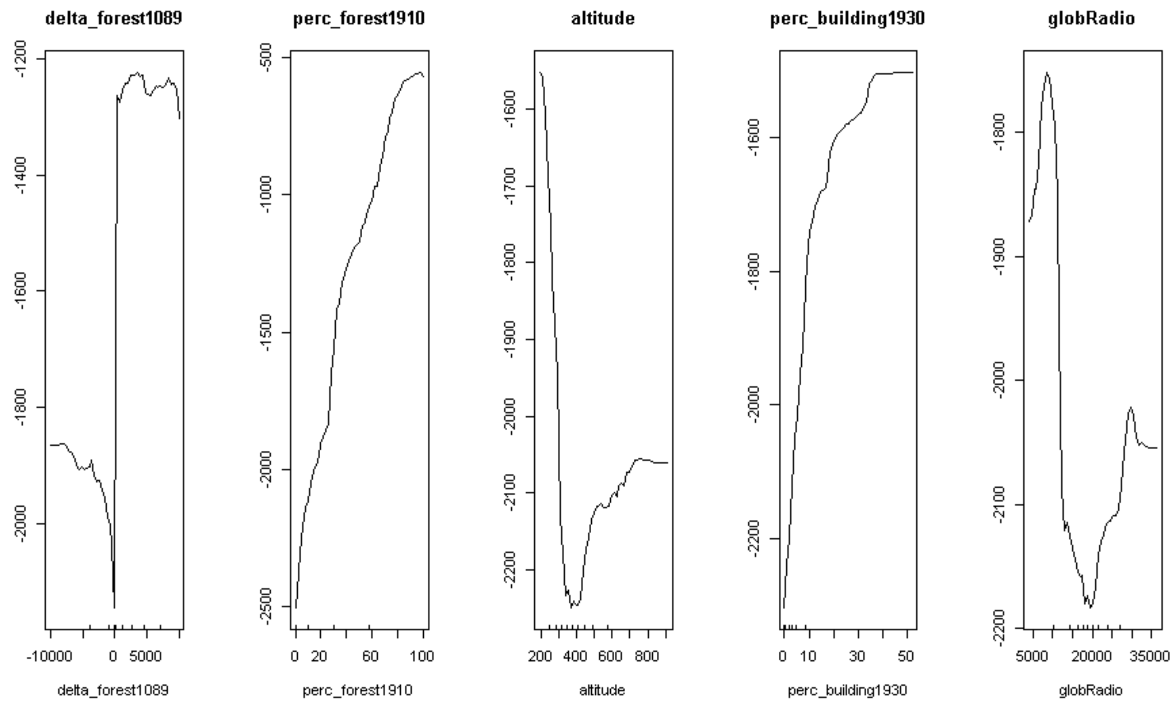

Figure 40 – Partial response plots of the five most important variables (except text attribute sezFederviti) according to Random Forest carried out on vineyard area change between 1934 and1989.

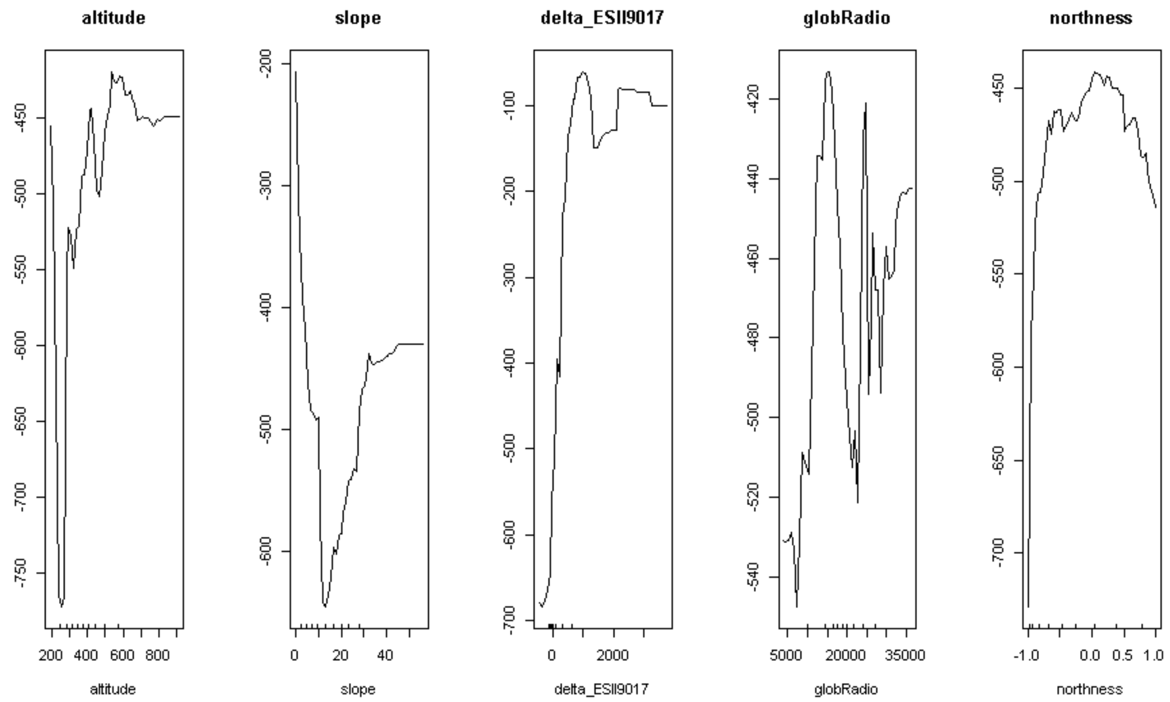

Figure 41 – Partial response plots of the five most important variables according to Random Forest carried out on vineyard area change between 1989-2018.

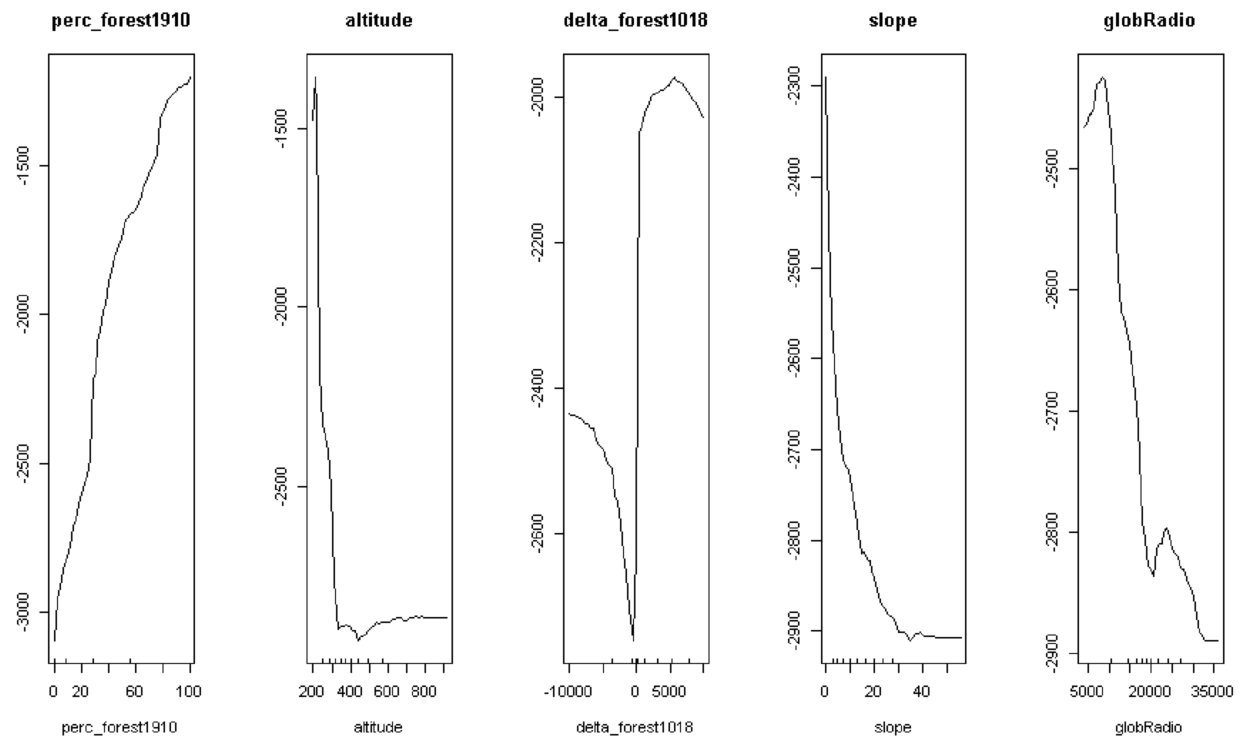

Figure 42 – Partial response plots of the five most important variables (except text attribute sezFederviti) according to Random Forest carried out on vineyard area change between 1934 and 2018.

Personal declaration:

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Giubiasco, 31.1.2021

Lisa Wyler