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Zurich<sup>UZH</sup>**

# Potential drivers of present distribution of *Robinia pseudoacacia* L. in the southern Alps, Ticino

GEO 511 Master's Thesis

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## Summary

*Robinia Pseudoacacia* L., a pioneering and invasive species of North America, was imported as an ornamental plant in the botanical gardens in France in the 1800s. Then, she was brought and planted in other countries in Central Europe. Its aggressive growth in various ecosystems posing a threat to biodiversity and native species, contrasts with its use in different production fields making it a controversial and discussed species. Despite this high interest, the factors driving the encroachment of the black locust are not fully understood yet and there is still the need for further research and clarification.

In three study sites in the Canton Ticino, potential drivers on the spread strategies of this invasive species were analyzed. One study site was inherited from a previous study (Burkhardt 2017), and the methodology, firstly revised, then applied to the new sites. The species distribution was mapped by using drone images taken during its flowering, when the species is best visible. Considered potential drivers, either orographic variables (altitude, aspect and slope), as well as anthropogenic- (land use classification, management intensity and its evolution, and distances from different features such as vineyards, roads, rivers), and natural disturbances (fires, rock falls and landslides) were considered to run a Monte Carlo Simulation. Then, by using the habitat suitability model MaxEnt, the presence of the black locust was generalized in the three study sites.

The result of the simulation shows very significant correlations for vehicles referring to the orographic features and the natural disturbances. This factor confirm its pioneering character. For the anthropogenic disturbances, medium and mature coppice stands and the evolution of land use management intensity are positively correlated with the encroachment of the species. Instead, for some anthropogenic variables related to distances, it was not always possible to find a plausible explanation for the resulting correlations. The response curves of the predicted variable of the MaxEnt modelling and the probability maps basically reflect the results of the simulation and confirm most of the initial hypotheses but not the thermophilic one of the species.

Although the used methodology contains some shortcomings, it was possible to show that the encroachment of the black locust is influenced by several parameters. Depending on the severity of disturbance, either natural or anthropogenic, and depending if the disturbance happened in the past (unmanaged coppices, fire events) or in the present (construction of a road, railway,...) the species colonization can be more or less aggressive. In any case, the combination of several variables at the same time does not always make the analysis obvious. This work can pose the foundation for the development of further management strategies for invasive species more in general and shows that there is the need to review the role of the black locust in the thematic of arboreal/woody invasive neophytes issue.

## Zusammenfassung

*Robinie Pseudoacacia L.*, eine Pionier- und Neophyten Art aus Nordamerika, wurde im 19. Jahrhundert als Zierbaum in den botanischen Garten in Frankreich importiert. Durch aktive Pflanzung in anderen Länder Mitteleuropas verbreitete sich die Art sehr schnell. Ihr aggressives Wachstum in verschiedenen Ökosystemen bedroht die Biodiversität und die einheimischen Arten aber ihre Verwendung in verschiedenen Produktionsbereichen gibt der Robinie eine bivalente Stellung. Trotz den grossen Interessen, sind heutzutage die Faktoren, welche die Verbreitung der Art bestimmen noch nicht vollständig geklärt und es besteht ein Handlungsbedarf weitere Forschung zu betreiben.

In drei Untersuchungsgebieten im Kanton Tessin wurden die Faktoren analysiert, welche einen potentiellen Einfluss auf die Verbreitung der Art haben könnten. Ein Untersuchungsgebiet von einer früheren Studie (Burkhardt 2017) wurde übernommen, und die dann überarbeitete Methodik auf die neuen Gebieten angewendet. Die Verbreitung wurde mittels Drohne-Bildern, welche während ihre Blütezeit aufgenommen wurde, kartiert. Als potentiellen Einflussfaktoren wurden orographische variablen (Höhe, Exposition und Hangneigung) sowie anthropogenen- (Bodenklassifizierung, Bewirtschaftungsintensität und ihre Entwicklung, Entfernung zu verschiedenen Variablen wie Weinberge, Strassen,...) und natürliche Störungen (Brände, Steinschläge und Oberflächenrutschungen) miteinbezogen um eine Monte Carlo Simulation durchzuführen. Mithilfe eines MaxEnt Modells zur Vorhersage der Artenverteilung, wurde dann die Verbreitung der Art verallgemeinert.

Die Ergebnisse der Simulation zeigen, dass die orographischen Faktoren sowie die natürlichen Einflussfaktoren positiv mit dem Aufkommen der Art korrelieren und bestätigen ihren Pioniercharakter. Für die anthropogenen Störungen, sind v.a. die Niederwalde im mittleren und ausgewachsenen Zustand sowie die Entwicklung der Bewirtschaftungsintensität ausschlaggebenden Variablen. Auf der anderen Seite war es für einige Distanz Variablen, nicht immer möglich, eine plausible Erklärung für die gefundenen Korrelationen zu finden. Der vorhergesagter Verlauf der Antwortkurven aus der MaxEnt Modellierung und die generierten Wahrscheinlichkeitskarten ihrer Ansiedlung Widerspiegeln die Ergebnissen der Simulation und Bestätigen die meisten der Hypothesen aber nicht ihren thermophilen Charakter.

Obwohl die verwendete Methodik einige Fehlerhaftigkeiten aufweist, konnte gezeigt werden, dass die Ansiedlung der Robinie von einigen Faktoren gefördert wird. In Abhängigkeit der Schwere von anthropogenen oder natürlichen Störungen, und abhängig davon, ob die Störung in der Vergangenheit (ungebrauchte Niederwälder, Feuer Ereignisse) oder in der Gegenwart (Bau einer Strasse, Eisenbahn,...) aufgetreten sind, kann sich die Art aggressiv oder moderat verbreiten. Die Kombination mehrerer Variablen machen aber die Analyse nicht immer offensichtlich. Diese Arbeit kann die Grundlagen für die Entwicklung

weiterer Managementstrategien für invasive Neophyten erweitern und zeigt, dass ein Umdenken notwendig ist, über die Rolle der Robinie in der Thematik der verholzten invasiven Neophyten.

## Riassunto

*Robinia pseudoacacia* L., una pianta pioniera ed invasiva proveniente dall'America del Nord, fu importata come pianta ornamentale nel giardino botanico in Francia nel 1800. Tramite attiva piantagione in tutta l'Europa centrale, la sua espansione aumentò gradualmente. La sua aggressiva crescita in diversi ecosistemi, rappresenta una minaccia per la biodiversità e le specie autoctone. Invece, il suo utilizzo in diversi campi di produzione la rendono una pianta altamente discussa. Oggigiorno i fattori che determinano maggiormente il suo insediamento non sono ancora del tutto compresi e c'è quindi la necessità di ulteriori ricerche e chiarimenti.

In tre aree di studio nel Canton Ticino, sono stati analizzati i potenziali fattori con maggiore influenza sulla sua espansione. Una delle aree è stata ereditata da uno studio precedente (Burkhardt 2017) e la metodologia, dapprima rivista, poi applicata alle nuove aree. L'espansione è stata mappata grazie a delle immagini riprese con il drone durante la sua fioritura. Come potenziali fattori sono state scelte variabili orografiche (altitudine, esposizione e pendenza), sia disturbi di tipo antropogenico (classificazione del territorio, intensità di gestione ed evoluzione del territorio, distanze da diverse variabili, come vigneti, strade,...) e disturbi naturali (incendi, caduta sassi, scivolamenti superficiali) per poi condurre una Simulazione di Monte Carlo. Dopodiché, utilizzando un modello MaxEnt, è stato creato un modello per generalizzare la distribuzione e la presenza della robinia nelle aree di studio.

Dalla simulazione di monte carlo sono risultate delle correlazioni significative per le variabili orografiche, specialmente per la pendenza e l'esposizione. Per i disturbi antropogenici, i boschi cedui allo stadio medio e maturo, l'intensità di gestione del suolo e la sua evoluzione sono anch'esse correlate positivamente. Anche le aree colpite da disturbi naturali sono risultati molto positivi, fattore che riconferma il suo carattere pionieristico. Invece, per alcune variabili antropogeniche relazionate alle distanze, non sempre è stato facile trovare una spiegazione plausibile per le risultate correlazioni. L'andamento delle variabili selezionate dal modello MaxEnt e le carte di probabilità d'insediamento confermano i risultati ottenuti nella simulazione e le ipotesi iniziali ma non il suo carattere termofilo.

Anche se la metodologia utilizzata contiene alcune lacune, è stato possibile mostrare che l'insediamento di questa neofita invasiva viene influenzato maggiormente da alcuni fattori. A seconda della gravità dei disturbi antropogenici o naturali, e a seconda se il disturbo si sia verificato in passato (cedui poco gestiti, incendio) o nel presente (costruzione di una strada, ferrovia,...) l'insediamento può essere aggressivo o meno. In ogni caso, la combinazione di più variabili contemporaneamente non sempre rende l'analisi conclusiva. Questo lavoro può porre le basi per lo sviluppo di strategie di gestione per le piante invasive più in generale, e dimostra che c'è la necessità di rivedere il ruolo della robinia nella tematiche delle piante arboree invasive.

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## **Abbreviations**

MCS	Monte Carlo Simulation
DTM	Digital Terrain Model
DEM	Digital Elevation Model
AUC	Area Under the Curve
IDW	Inverse Distance Weighted
PCA	Principal Component Analysis

# **1. Introduction**

## **1.1 Scientific background**

### 1.1.1 The invasive neophytes issue

The process of globalization, environmental change, tourism and increasingly modern freight traffic have significantly increased the numbers of human-introduced species (BAFU 2016). Due to suitable sites-, and climate conditions, invasive species have been able to spread in natural communities and adjacent forests of Europe over the last decades creating different kind of damages and problematics (Nobis 2006).

The definition of invasive neophytes is conventionally connected to the discovery of America, in particular to the starting point of worldwide trade of goods. According to the international definition, "Invasive neophytes are alien species that were introduced after the year 1500 as a result of human activity and that establish themselves in natural or semi-natural ecosystems or habitats, causing ecosystem changes and threatening their native communities. Invasive neophytes spread efficiently and cause damage in the areas of biodiversity, health and/or the economy" (Sanu et al. 2005). Only if a neophyte is able to penetrate into existing ecosystems and to create damages, the species is then labelled as invasive (Kowarik 2003; Nobis 2006).

Depending on site-specific characteristics, environmental conditions, ongoing forest management processes and the neophyte characteristic itself, the effect of invasive neophytes can either alterate normal ecosystem processes, threat biodiversity, increase species competition or even decrease native communities (Campagnaro, Brundu, and Sitzia 2017). The worst case is when the invasive neophytes completely replaces the native ecosystem vegetation (Lazzaro et al. 2017). This overall process is called biological invasion, and is considered the most important factor endangering biodiversity (Rejmánek 1996).

For the purpose of this thesis, we will only consider woody or arboreal invasive neophytes as potential invaders. In some cases, they have the possibility to invade deciduous forest stands and nature conservation forests (Grund et al. 2005), endangering their species composition, forest microclimate and soil chemistry (Walter et al. 2005). Most of such neophytes occur in warm lowland and near settlements. Usually, this species are deliberately introduced neophytes used in horticulture and have the possibility to became naturalized. However, they seldom appear in the closed forest, exceptions are forest roads, forest edges and especially where the forest is clearer. Harvesting and development measures can thus promote the occurrence of neophytes, as well as disturbances caused by natural events (storms, fires). Under such conditions, woody or arboreal invasive neophytes, which usually

grow outside the forest, can spread on rejuvenation areas or in sparse forests hindering the natural forest rejuvenation process (Nobis 2006).

### 1.1.2 Steps toward a biological invasion

The steps towards biological or species invasion can be represented in different stages. “The invasion curve” (figure 1), shows the typical phases towards a biological invasion, and the four related categories of invasive neophytes management. After the introduction stage, characterized by a low abundance and scattered distribution of the neophyte, suitable site- and climatic conditions can favour the establishment of small populations. If the abundance and the infested area increases, public awareness typically begins and management options start to be taken into account. When the invasive neophyte gets even more widespread and abundant, the native communities of an ecosystem can be completely replaced (Lazzaro et al. 2017; Harvey and Mazzotti 2014).

The stages of species invasion are strongly connected to different economic and ecological effects (figure 1). The exponential curve of the invasion process indicates decreasing management options and increasing financial costs to control the invasive neophytes. First of all, the most important and cost-effective option is to prevent the establishment of invasive neophytes. Avoid the importation and the trade of invasive neophytes are some prevention examples. Until there are small numbers of localized populations, the eradication represents a cheap and feasible method. However, as soon as the abundance increases, the eradication is not further possible and the containment of the established population usually begins. This, in most of the cases, includes intense efforts. When the distribution is too widespread and abundant, the resource protection & long-term management is the ultimate option. Here, especially highly valued resources are protected and the distribution of the invasive neophyte is reduced to the lowest feasible level (Harvey and Mazzotti 2014).

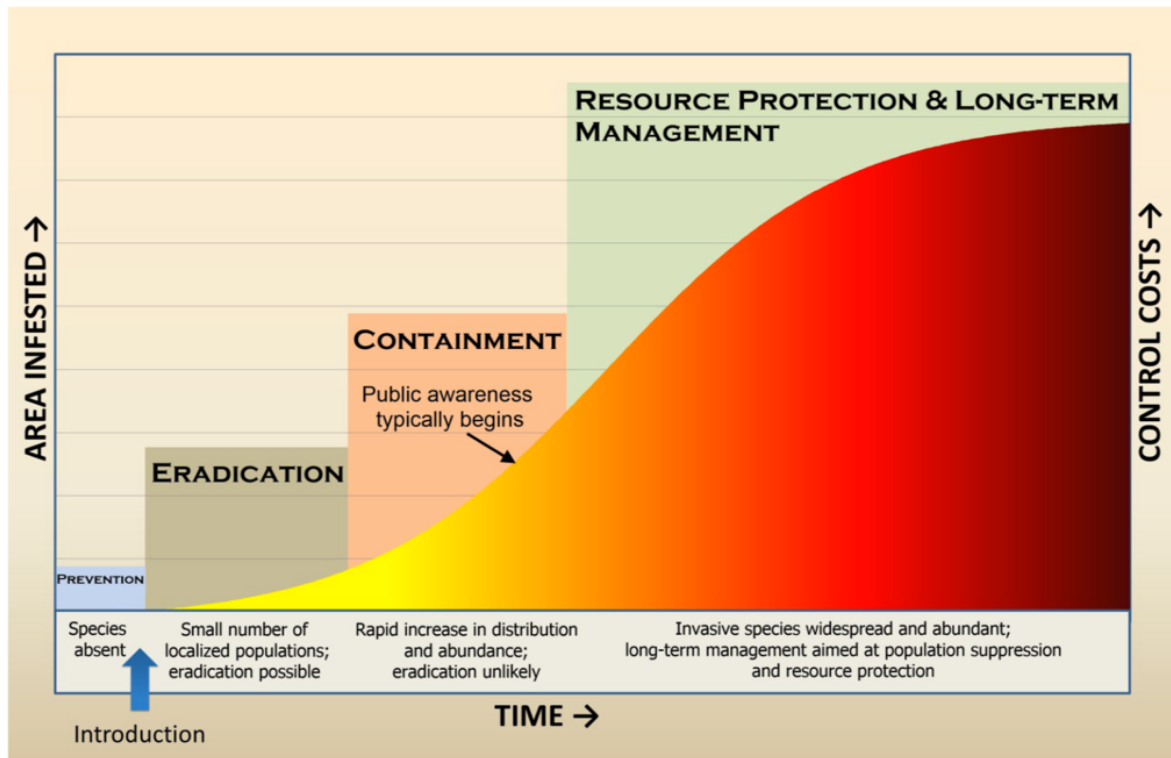


Figure 1: The invasion curve. Overview of the steps toward a biological invasion (Harvey and Mazzotti 2014)

### 1.1.3 Situation in Switzerland

Considering Switzerland, especially warm low-lying forests on the southern Alps, are already affected by invasive species. Fortunately still locally limited. According to Nobis (2006), 12% of all vascular flora are neophytes and the proportion is steadily increasing, mostly due to climate warming, different disturbances and the use of ornamental plants in horticulture (Moser et al. 2002).

By far the most common woody/arboreal invasive neophyte in the southern Alps (figure 2) is the black locust (*Robinia Pseudoacacia* L.), listed in the “blacklist” (Info flora 2014) of invasive introduced species. This list contains 23 neophytes which have been addressed from the “Swiss Commission for the Preservation of Wild Plants” (SKEW) as particularly invasive. From these, six are arboreal/woody species (Nobis 2006). Other 21 neophytes are on a warning list, the “watchlist” which is monitored (Nobis 2006; Sanu et al. 2005).

With the ongoing consequence of climate warming, higher temperatures have the possibility to make the spread of woody/arboreal invasive subtropical and tropical neophytes, more accentuate in the already affected areas (BUND 2015). According to the mean annual temperature observations in Switzerland over the last fifty years, the Canton Ticino, the midland and the alpine dry valleys are the most susceptible (MeteoSvizzera 2012). Nonetheless, due to the alpine chain acting as a natural barrier and a consciousness

management against invasive neophytes in the north of Switzerland, the impacts are still reduced. Instead, the southern part of Switzerland is experiencing a different scenario. The considerable amount of incoming invasive neophytes, their widespread distribution and favourable climatic conditions, doesn't permit an efficient and cost-effective management. For this reason, the authorities and scientists are trying to avoid a further expansion of the existing species and to find strategies to reduce their negative impacts (Sanu et al. 2005). Basically, instead to adopt a segregative approach separating areas with and without invasive neophytes, the integrative approach tries to combine both aspects including trade-offs and challenges (Kraus et al. 2013)

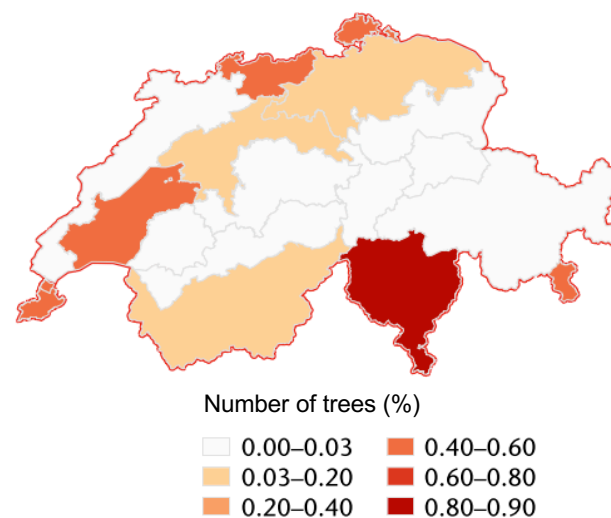


Figure 2: Black locust distribution in Switzerland, expressed as percentage (%) of the total number of trees (Nobis 2006)

According to the “Federal Act on the Protection of Natural and Cultural Heritage (NCHA)”, it is not permitted in Switzerland to plant invasive species in natural areas without permission (Art. 23, NCHA, 1996) and the Ordinance on the Handling of Organism in the Environment among other things, regulates the use of invasive organism (Art. 15-16, Annex 2, RO, 2008). However, the careless use of invasive species as ornamental plants on private grounds made the dispersal of propagule sources more intense (Weber 2000).

## 1.2 The black locust (*Robinia Pseudoacacia* L.)

### 1.2.1 Encroachment history and its distribution

The black locust is a pioneer tree, native to North America, imported for the first time in Europe in 1601 from Jean Robin, botanist of the King of France (Mühletaler 2010; Cierjacks et al. 2013). In the beginning, the species was introduced as a rare ornamental plant in botanical gardens overall in Europe. Then, it became recommended for large-scale afforestation and therefore quickly invaded Central Europe. This process was encouraged by extensive planting (Vítková et al. 2017; Enescu and Danescu 2013).

The ongoing need to increase wood production and the need to stabilize slopes against natural hazards during the industrialization, made possible the so-called “black locust mania”, starting in the early 19<sup>th</sup> century (Vítková et al. 2018). In order to maximize the timber production during the 20<sup>th</sup> century, black locust stands were usually coppiced at 6 – 30 years intervals (Vítková et al. 2018; Mühletaler 2010). This forest management strategy, consisting of repeated clear-cut, provide wood products in short time. In fact, the short rotation time was required for coal production, and the grazing in the forest encouraged heavy stand thinnings. This silviculture management particularly favoured the additional spread of the species in deciduous forests (Manetti et al. 2016; Vítková et al. 2017). Unfortunately, foresters detected a decline in timber production after two to three rotations, probably caused by exhausted soils and impoverished herb layer (Manetti et al. 2016; Vítková et al. 2017; Vítková, Tonika, and Müllerová 2015).

The black locust presented other successful characteristics, making the species even more attractive. The long-lasting quality of its timber, resistance to fungi and root-system made the species highly valued for different applications (Vítková et al. 2017; Mühletaler 2010).

After the Second World War, the species easily encroached abandoned areas in different European countries (Hungary, Czech Republic, Italy) as well as the southern slopes of the Swiss Alps. Meanwhile, the black locust has become part of the ecosystems and the cultural landscape in many areas, so that neither a unrestricted cultivation nor a large-scale eradication makes sense (Mühletaler 2010; Vítková et al. 2018; Brändli 1998). (Sanu et al. 2005).

### 1.2.2 Biological characteristics

The black locust is a deciduous, broad-leaved, light-demanding pioneer tree that belongs to the large plant family of the Leguminosae (or Fabaceae). In general it's a fast-growing tree with rapid juvenile growth, can reach heights of 30m and presents greyish-brown bark, which becomes longitudinal fissures with age. The branches are armed with spines, making forestry not always comfortable (Cierjacks et al. 2013; Vítková et al. 2017). The species natural longevity ranges around 90 – 100 years, making it particular suitable for the coppice silvicultural strategy (Enescu and Danescu 2013).

The leaves are imparipinnate, usually 20 – 35cm long arranged alternately on the stem. The leaves are fast-decomposed and generate a high quantity of organic matter which then in turn contribute to the soil formation process (Enescu and Danescu 2013).

The fruits are typical brown pod legume and the brown seeds are usually too heavy to fly over long distances. Even if the species can reproduce either generatively or vegetative, the vegetative way is more common (Enescu and Danescu 2013).

The flowers are arranged in loose drooping clumps named racemes and can produce a large amount of nectar. The flowering occurs between May and June with typical white-yellow flowers (Cierjacks et al. 2013).

The root system presents nitrogen bacteria which are able to fix atmospheric nitrogen bringing some nutrients and energy advantages to the species. This can disfavour rare herbaceous plants that usually colonize poor sites (Mühletaler 2010), or enrich soil nitrogen stores (Lazzaro et al. 2017). The far-reaching dimorphic root system can grow downwards to a depth of about 8m, making the species appropriate for slope stabilization (Enescu and Danescu 2013).

### 1.2.3 Ecological requirements and risks

Since the black locust has low ecological needs and is extremely resistant to disturbances, the species can grow in a wide range of habitats (urban areas, agricultural landscape, dry grassland, forests). It can grow on different soils, as well as on shallow young soils (cambisols, leptosols and arenosols) and is tolerant to droughts, salinity or low/high pH values (Mühletaler 2010; Vítková, Tonika, and Müllerová 2015). Besides the pioneer behaviour, which in most of the cases tends to quickly encroach abandoned fields, pastures and open suburban areas, also forest gaps can be quickly colonized (Vítková et al. 2017).

Due to the heliophile behaviour, the species tends to dominate early stages of forest regeneration (Enescu and Danescu 2013). Heliophile means that during the juvenile age the species needs much light to grow, whereas in the further growing phases, under unfavourable light conditions, it can develop a persistent bud bank on roots, stems and branches. Though the species is shade-intolerant, this enables a rapid reaction to canopy opening and therefore permits a fast encroachment of different ecosystems (Vítková et al. 2017; Mühletaler 2010).

Although the encroachment of black locust is very successful, according to Vítková et al. (2017) and Mühletaler (2010) their distribution over Central Europe is constrained by:

1. Soil properties: lack of oxygen in soils
2. Climate: Frost, especially in late spring combined with a short vegetation period and generally cold climate
3. Disturbances: continuously heavy trampling, meadows and arable fields
4. Orography: elevation, slope

Consequently, the most often encroached areas of black locust in Central Europe are:

1. Dry and semi-dry grasslands
2. Shrubland and dry forest
3. Alluvial habitats
4. Abandoned agrarian fields, vineyards, hedgerows, roadsides
5. Industrial and urban areas including polluted or salty soils



#### 6. Disturbed areas, e.g. post fire sites, windthrows, previously flooded areas

Nonetheless, the establishment of new black locust populations is difficult. Even if the reproduction can be either vegetative or generatively, the rather heavy seeds don't permit an efficient dispersal and is therefore uncommon. The seeds are primarily influenced by the gravity and distributed by the wind activity in the proximity of the mother tree. The dispersal over long-distances is primarily influenced by human activities (Pividori M. 2003; Li et al. 2018; Lazzaro et al. 2017). Hence, the vegetative reproduction is more successful. The species has an incredible capacity to build underground runners which then enables to form replicates (Cierjacks et al. 2013).

The low ecological needs of the black locust, the pioneer behaviour, and the ability to enrich soil nitrogen stores, made the impact on ecosystem more or less severe. On the other hand, the competition with native species, and the enrichment in soil nitrogen can lead to a sharp increase in productivity, impacting species richness- and composition of ecosystems (Vítková et al. 2017; Lazzaro et al. 2017).

#### 1.2.4 Management practices

Firstly introduced as a rare ornamental plant in botanical gardens, through the years, useful other characteristics of the species were discovered. According to the long historical tradition, due to the thick and penetrating root system, it was especially adopted for slope stabilization against natural hazards and therefore planting was encouraged. Then, in order to maximize the wood production during the industrialization, black locust stands were more and more coppiced. However, without forestry, it was noted that the abundance of the species and the timber production would decrease and highly competitive shade tolerant trees will suppress the species. On the other hand, natural succession of abandoned black locust stands towards original plant communities is low, problematic, costly, and time-consuming (Manetti et al. 2016; Vítková et al. 2017; Vítková and Kolbek 2010; Pividori M. 2003).

Today, in many parts of Central Europe, black locust stands are still coppiced, and wood production remains one of the main purposes of the species. Especially in Hungary, Romania or Italy, stands with exceptional provenances and a certain degree of forestry, promise astonishingly lucrative results in a short period of time (Mühletaler 2010). The high-valuable wood, and the long-lasting quality of its timber, resistance to insects and fungi make it especially useful for the production of firewood, garden furniture, balcony and poles. Additionally, his biomedical properties can be used in herbal medicine, the leaf for making animal forage and even honey production is well appreciated (Vítková et al. 2017).

In general, because of its positive economic but negative environmental impacts and conflict of interest over its value over different groups/stakeholders, as many other invasive

arboreal/woody neophytes, it remains highly disputed and controversial (Vítková et al. 2018; Lazzaro et al. 2017).

### **1.3 Knowledge gap**

Invasive neophytes can have drastically negative effects on ecosystem processes. Of particular concern are protected and sensitive ecosystems in Europe, and stands used for forestry purposes. Unfortunately, the impact of invasive neophytes are frequently less well understood as compared to other pressures on protected areas (for example, land use change) and therefore need special attention (Campagnaro, Brundu, and Sitzia 2017; Lazzaro et al. 2017; Nobis 2006). Especially in Switzerland, the unwanted spread of invasive neophytes is increasingly perceived as a problem and the need for effective control measures are requested (Sanu et al. 2005).

The black locust is a first generation invasive neophyte present on the southern Alps since the middle of the 19<sup>th</sup> century, and today, according to literature, observation, local expert knowledge and available data, the distribution in the southern Alps is naturalized and stable, making it a model species to understand the distribution dynamics of invasive neophytes on a longer run. Even if the spread is mostly context-dependent it highlights the need for a better understanding of its temporal and spatial variability, particularly within sensitive ecosystems (Campagnaro, Brundu, and Sitzia 2017). Besides the importance of climate change, the expansion of urban areas, the abandonment of areas, the increasing mobility, and the inappropriate use of ornamental plants, continues to favour the spread of invasive neophytes (Sanu et al. 2005). In this context, the land use change is supposed to drive the distribution of many invasive neophytes, included the black locust (Muster, Elsenbeer, and Conedera 2007; Brovkina et al. 2017). An accurate and carefully monitoring of these species is therefore indispensable (Weber 2000). A closer look on the distribution of the black locust in the southern Alps and the potential drivers which favours its temporal and space variability, represent a starting point for further research, and has great potential to understand the future distribution of other arboreal/woody invasive neophytes (Campagnaro, Brundu, and Sitzia 2017; Nobis 2006).

Many studies in Europe have primarily focused on the physiology of the black locust, trying to understand how the species reproduce and grow, including the parameters influencing the species' fitness (Casari, 1998; Pividori M., 2003; Bonacina, 2014; Vítková et al., 2017, 2018). However, there has been little to no research on the distribution and the spread strategies of this invasive neophyte in the southern slopes of the Swiss Alps. Understanding the colonization strategies of this arboreal invasive neophyte opens new strategies to adapt future management options for other invasive neophyte which are still in the spreading phase today. Developing a more integrated approach which assesses the

effects of invasive neophytes on several response variables instead to focus only on one variable at the time opens new horizons for the further understanding of invasive spreading dynamics (Hulme et al. 2013). This also opens new approaches even to modelling the distribution of invasive neophytes in the southern Alps. Although species distribution models exist (for example the standard niches and distribution model MaxEnt) and have widely been used to model habitat suitability of different species, even neophytes, a specific model for the distribution of the black locust is lacking.

In a recent Bachelor thesis by Burkhardt (2017), the distribution (e.g. mapping) of the black locust and the main potential drivers of its spreading have been investigated in a study site between Gudo and Sementina (TI). This methodological approach opens new perspectives for understanding the spreading dynamic of the species and will be deepened in this master thesis.

#### **1.4 Research question, hypothesis and objectives**

The aim of this master thesis is to monitor and map the black locust in the Canton Ticino, Switzerland, and to analyse and determine the most influential factors which foster or inhibits the spread and growth of the species in the study sites.

The research questions are therefore related to assess the relative importance of potential drivers of the species presence in the southern Alps. In particular, we selected three study sites in the southern Alps, for mapping the distribution of the species and to analyse following potential drivers on its encroachment processes:

- 1) Orographic parameters**
- 2) Anthropogenic disturbance**
- 3) Natural disturbances**

Then, even a few hypothesis have been elaborated and will be verified:

- 1) The black locust encroachment is influenced by the land-use change, especially by the different coppice stands
- 2) The black locust firstly encroaches open areas or poorly managed one, e.g. areas that have opened up following a natural disturbance or areas which have been abandoned
- 3) The black locust encroachment is influenced by orographic parameters, more precisely, foothill zone exposed to the south seems to be particular suitable
- 4) Since the black locust has a long tradition to be used for slope stabilization, we suppose that areas in proximity to railways and roads are especially suitable

To this purpose we integrated the already mapped area by Burkhardt (2017) with two other study sites. The methodological mapping and analysis approach used by Burkhardt (2017) was firstly verified and then adopted to all three sites.

Finally a MaxEnt modelling approach has being applied on the three study sites in order to highlight the most significant drivers of the black locust distribution on the southern Alps.

## **2. Materials and methods**

### **2.1 Study area**

#### **2.1.1 Study sites**

According to the already available data and by looking at the abundance of the black locust populations, three study sites in the southern Alps, were selected. Two in the most southern part of the Canton Ticino (figure 3, point A and B), in a forest and settlement dominated hilly region called Mendrisiotto, whereas the third one is located between Gudo and Sementina on the Magadino plain (figure 3, point C).

Nearly most of the study site in Stabio (45°50N 8°55E) presents enlarged black locust populations, whereas Chiasso (45°50N 9°E) presents a variety of different interesting features, ranging from forest to vineyards to urban areas. Overall, these two study sites cover an area of about 1.5 km<sup>2</sup>. Instead, the study site of Sementina (46°18N 8°96E) covers an area of 1,98 km<sup>2</sup> and presents black locust populations mainly distributed on the foothill zone exposed to the south and some isolated populations in rock fall areas.

The altitude of the study sites of Chiasso and Stabio ranges between 230 and 440m s.l.m. and the slopes are relatively small but in some part can reach 45%. The study site in Chiasso is primarily dominated by coppices at different stages, chestnut- and mixed forest, some vineyards and sporadic urban areas, whereas the study site in Stabio is mainly characterized by industrial and agricultural areas and also coppice stands at different stages. Instead, in the study site of Sementina the altitude ranges from 206m s.l.m. at a maximum of 606m s.l.m., with slopes of up to 64%. This study site is mainly covered by mixed chestnut forests, some inhabited areas and several vineyards. However, due to cultural and historical reasons, the study sites experienced in some areas, noticeable land use change. For example, due to the decrease of wine activity in the recent years, many vineyards have been abandoned or transformed into urban areas.

Note that since the study site of Sementina has already be analysed by Burkhardt (2017) and was inherited for the purposes of this thesis, it will not be further explained in detail. For more details about the study site and results consult Burkhardt (2017). The methodology used in Burkhardt (2017) will then firstly be verified and then applied to the other two study sites in order to generate a model of the distribution of the black locust.

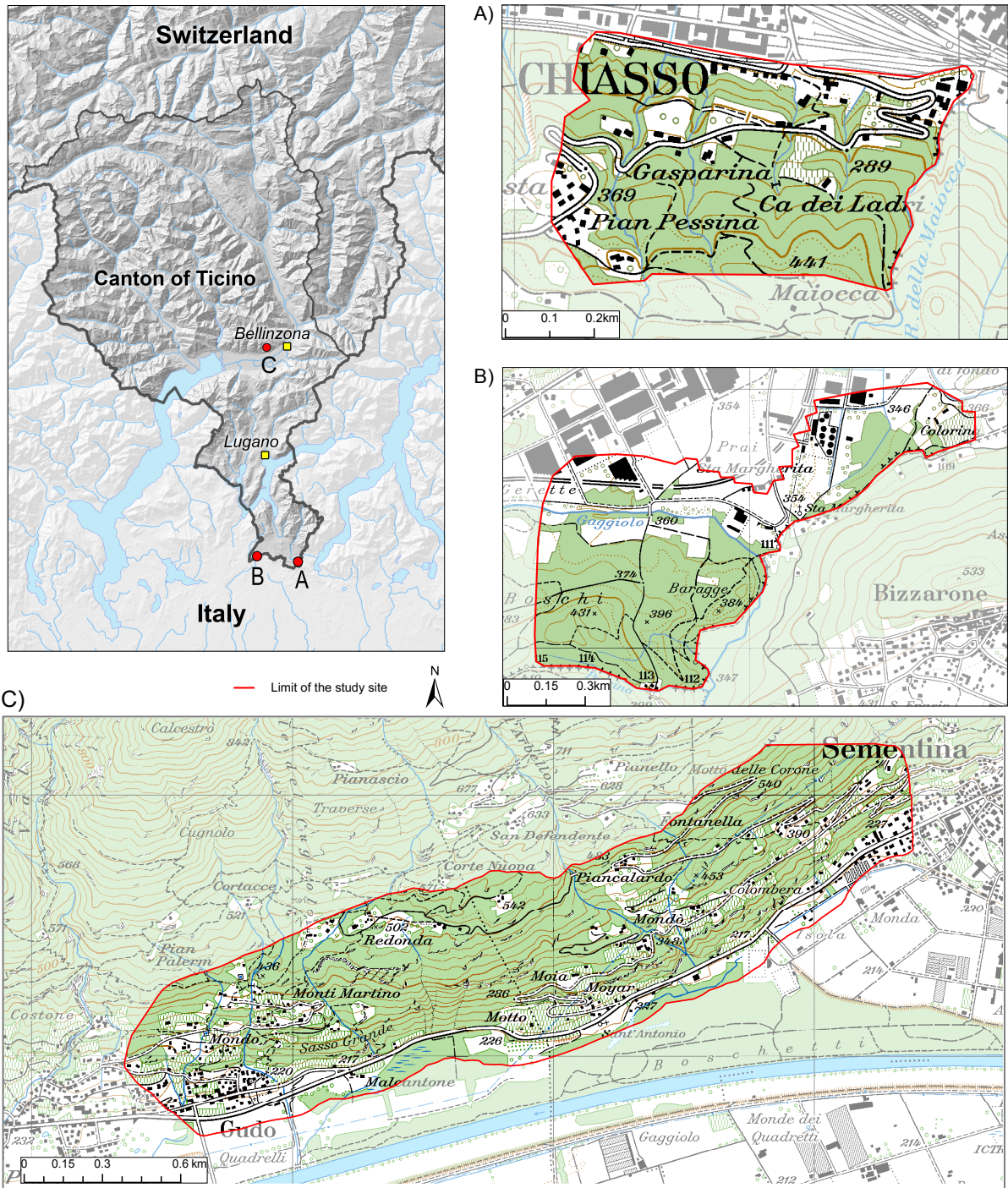


Figure 3: Overview of the study sites in the southern Alps, A) Chiasso, B) Stabio, C) Sementina

### 2.1.2 Climate and geology

Since the distance between the two study sites of Chiasso and Stabio is rather small (approximately 7km), we presume that there will be only small climatic differences or even none, and therefore the climate and geology is only described once.

The Alpine chain influence many meteorological (and consequently climatic) process in the southern Alps, attenuating or reinforcing its effects. The regions near the basins of the Verbano and Ceresio lakes, which remains protected from the Alps, are subject to the direct

influence of the currents of the Po valley. This special conformation gives rise to a typical climate named insubric, which is typical for the study sites. The insubric climate is characterized by dry and sunny winters, windy periods from the north (“favonio”) but also abundant snowfalls, very wet periods in the transition seasons (spring and autumn) and sunny summers interrupted by heavy storms (MeteoSvizzera 2012; Telesca et al. 2010).

Based on the meteorological station of Stabio (figure 4), the mean annual precipitation ranges between 1500 – 1700 mm and the mean annual temperature between 10 – 12 °C (Meteosvizzera 2018). These conditions are, for some subtropical and tropical invasive neophytes especially suitable for their expansion (Sanu et al. 2005).

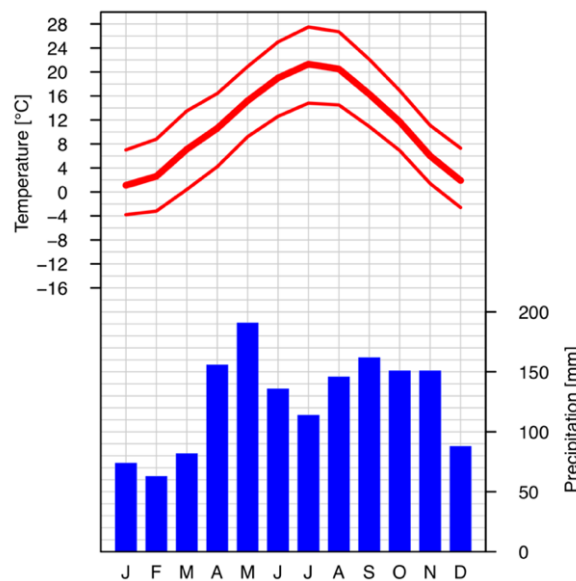


Figure 4: Climatic diagramm of the meteorological station of Stabio (Meteosvizzera 2018)

From a geological point of view, the study sites are part of the “Gompholite Lombard” formation, a set of rock formations from the Oligocene and Miocene, and of the “Chiasso formation” from the Oligocene. The latter consists prevalently of marl, subtle levels of sandstone and canaliform conglomerates. Instead, the “Gompholite Lombard”, prevails of conglomerates and sandstones. Locally, even sediment can be found, e.g. marly or marly-arenaceous. In addition, this formation, is divided into various other, named according to their locality, e.g. Conglomerate of Como, Val Grande sandstone (Gelati, Napolitano, and Valdistorlo 1988).

The surfaces of the two study sites are characterized by the presence of glacial- and fluvial sediments deposited by numerous advanced glaciers of the Alps during the last glaciation maximum (LGM). The sites, especially the lower Mendrisiotto, was affected by a branch of the Adda glacier. The rocks are either quaternary unconsolidated or clastic sedimentary and the main present lithological groups are sand, gravels, cobbles, conglomerates and breccias. Even clay, silt and sabbie can be found in many parts of the sites (Swisstopo 2018).

## 2.2 Methodological workflow

The conceptual diagram visible in figure 5 provides an overview of the working-steps of this master thesis. We first combine and elaborate different data sources and generate different variables, in order to discover if the distribution of the black locust has a site-selective behaviour or not. In the conceptual diagram, the potential drivers on the encroachment processes are subdivided into three dark green boxes and the light-green boxes show the data which will be used for the analysis. The orange boxes denotes the Monte Carlo Simulation (MCS) and the model generation whereas the red one indicate the expected results. Finally, the blue rectangles stands for the technical methods, e.g. programs which will enable the data processing and evaluation. In general, the methodological mapping and analysis approach used by Burkhardt (2017) will be firstly revised and then adopted to the study sites.

The orographic parameters will be extrapolated from the Digital Elevation Model (DEM), whereas the historical and present land use classification will be done based on historical aerial-photographs and daily used datasets. The land use classification will then be used to analyse the temporal evolution of the land use management intensity, variable which is supposed to be very crucial for the distribution of the black locust. Instead, further potential anthropogenic drivers like distances from different features such as roads or vineyards, were chose according to ongoing knowledge about the species and based on the consulted literature (Vítková et al. 2017; Burkhardt 2017; Muster, Elsenbeer, and Conedera 2007; Brovkina et al. 2017; Wagner and Fraterrigo 2015; Buzhdygan et al. 2016; Mühletaler 2010; Vítková, Tonika, and Müllerová 2015; Walter et al. 2005). On the other hand, the drone images and different SWISSIMAGEs, will provide the basis for the black locust mapping. The mapping will then be controlled by a fieldwork. Instead, the natural disturbances will be digitalized by consulting different databases.

Combined, all these datasets and generated variables will be used to run a Monte Carlo Simulation, which will enable to discover the most influential parameters which drive the distribution of the black locust in the study sites.

Finally, once compared all the results between the study sites, a species distribution model which can potentially be applied to other sites will be generated. For this purpose the already analysed study site of Sementina was inherited and included into the analysis. Before generating the model, the revised methodology of Burkhardt (2017) will be adopted to the study site of Sementina and the data included for the model generation.



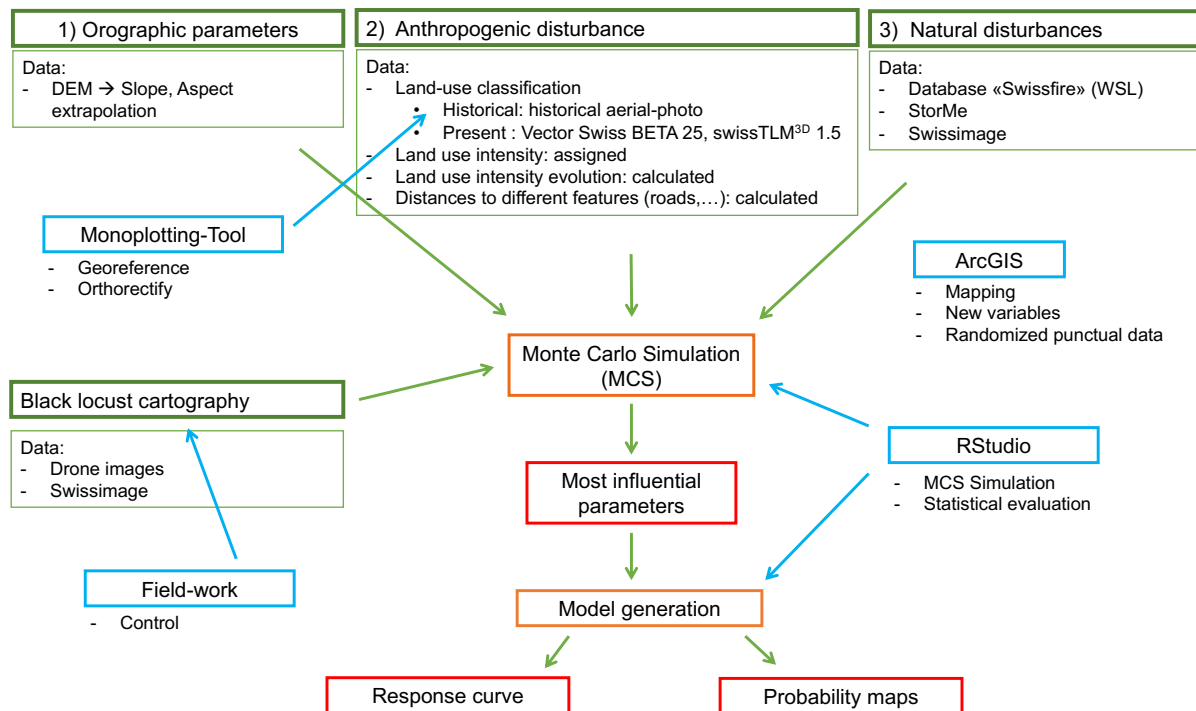


Figure 5: Conceptual diagram of the methodological workflow. The diagram is subdivided into different rectangles with different colors, each color indicating a different denotation.

The geographical information system ArcGIS (version 10.5) will be used to digitalize the mapping part of the black locust, to create overview and surface maps and comparison of images of the same area over different years. Also, the generation of new variables to detect the temporal evolution of the land use classification and management intensity and the generation of the randomized punctual data further used for the MCS will be operated by using the ArcGIS-tool. Instead, the MCS, the model generation and further statistical analysis will be achieved with the program “RStudio” (Version 1.1.447). Finally, the Monoplotting-tool will be used to georeferenced and orthorectify the historical aerial-photographs.

## 2.3 Data acquisition

### 2.3.1 Digitalization of the orographic parameters

Digital elevation models (DEM) are a useful and cost-effective device for calculating and summarise different land surface information. A 2m digital terrain model (DTM) of overall Switzerland was made accessible from the WSL and further modified to extrapolate the slope and the aspect, thought to be important terrain parameters for many types of environmental applications (Hunter and Goodchild 1997; Irfan Ashraf et al. 2012; Pauchard and Alaback 2004).

The surface slope represents the maximum rate of change in value from a cell to its neighbours, and can be calculated with different algorithms and expressed in degrees or percent (ArcMap 2016). Instead, the aspect can be understood as the slope direction and is always expressed with positive degrees, ranging from 0 to 360° in clockwise direction. Each cell then expresses the direction that the surface faces at a specific point (ArcMap 2016a).

Both operations apply 3x3 moving windows that pass over each cell in the input elevation raster and apply the specific algorithm. Basically, by using an averaging method and a third-order finite difference equation, the slope and the aspect are calculated incorporating the values of the eight neighbours cell's (Horn 1981).

### 2.3.2 Digitalization of the distribution of the black locust

In order to understand and analyse the temporal variability and distribution of the black locust in the study sites, the species was firstly mapped and then compared to already existing datasets.

The present distribution of the black locust was established by analysing drone images which were already taken in May 2017 (figure 6A – B) during its flowering, the period where the species is best visible due to its abundant white-yellow flowers. The black locust areas were mapped through polygons in ArcGIS. A further dataset with a mapping of the black locust of the overall Canton Ticino was already achieved during the 80s and made accessible in order to control the reliability of the mapping. Indispensable, the field-work permitted to control the accuracy of the mapping. Then, where it was needed, the mapping of the black locust was adjusted or missing areas were added.

Instead, to digitalize the historical distribution of the species, we assumed that between 1940 – 1950 their expansion in the southern Alps was just at the beginning and its presence in the forests supposed to be only minimal. Therefore we assumed that the historical mapping is negligible. The lack of reliable and consistent data during these years and the difficulty to interpret historical aerial photographs made this assumption acceptable.

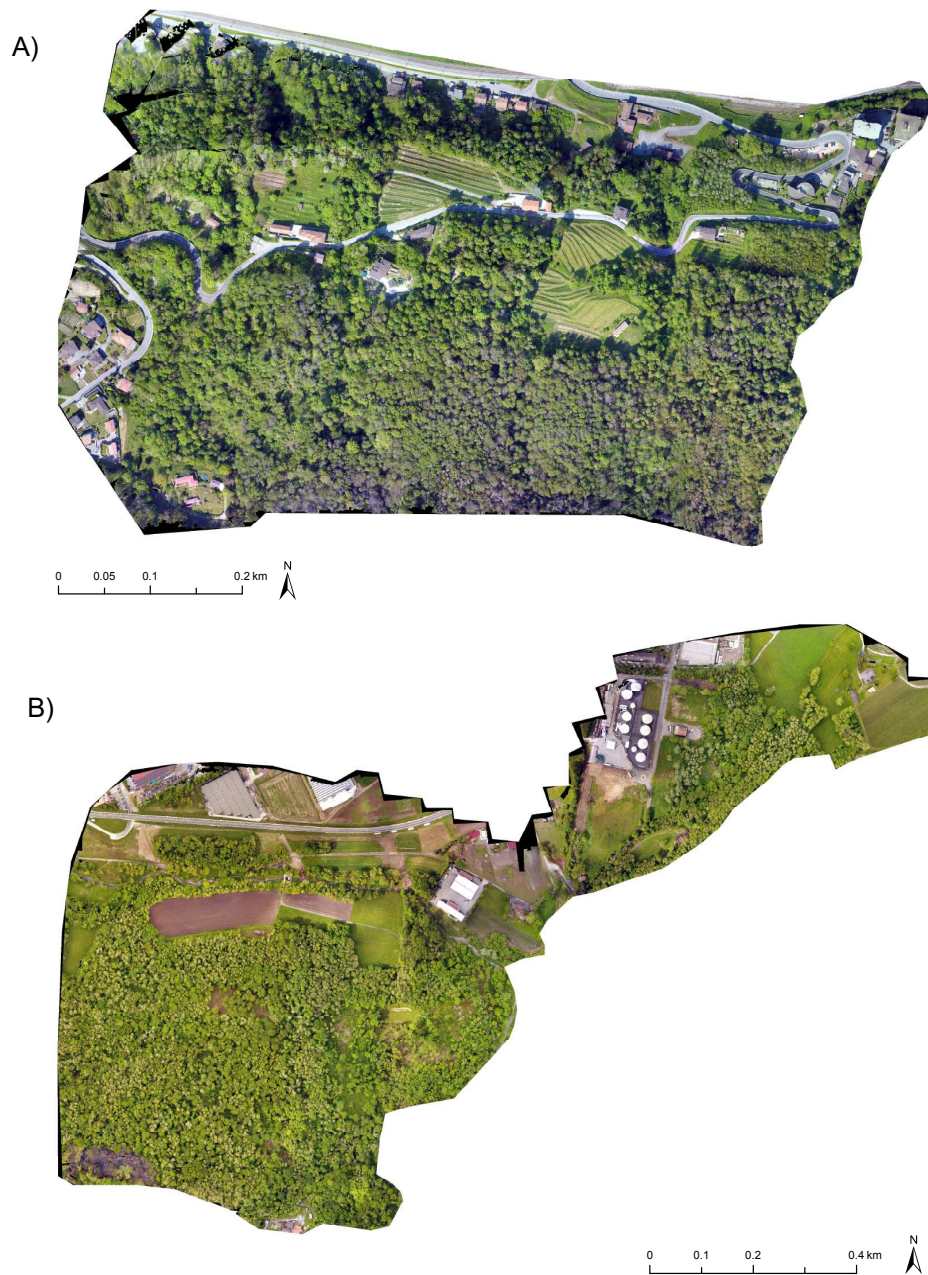


Figure 6: Drone images of the two study sites utilized for the black locust mapping. A) Chiasso, B) Stabio

### 2.3.3 Digitalization of the land-use classification-, management intensity- and evolution

The digitalization of the land use classification was done independently for each study site for the two interested periods, the 1940 – 1950 (historical classification) and 2017 (present classification). Only in this way, a temporal land use evolution- and management intensity analysis was possible.

For the historical and present classification, 19 categories were defined (table 1), assigning each piece of land, e.g. polygon in ArcGIS to a specific land use category. The 19 categories were chosen according to the features visible in the historical images, the present SWISSIMAGES and according to Burkhardt (2017).

Table 1: Overview of the 19 categories used for the historical and present land-use classification

Category number	Category description
0	Vineyard with house
1	Vineyard
2	Agricultural area
3	Meadows and other use
4	Urban area
5	Cultivated land area
6	Main roads
7	Side roads
8	City&road alleys
9	Riparian forest

Category number	Category description
10	River (with riverbank)
11	Railway
12	Young coppice stage 1
13	Medium coppice stage 2
14	Mature coppice stage 3
15	Old coppice stage 4
16	Gardens and other uses
17	Industrial area
18	Rural roads

Note that the category “Meadows and other use” includes cattle, breeding and pastures whereas the category “Gardens and other uses” incorporate either normal yards around houses or either simple grassland around different kind of infrastructures without a specific function.

Because since the 20<sup>th</sup> century, the black locust stands were usually coppiced (Manetti et al. 2016; Vítková et al. 2017), we suppose that most of the forests identified in the study sites belong to that type of silviculture strategy. According to the degree of canopy cover visible on the aerial images and on the SWISSIMAGEs, the coppices were divided into four additional categories indicating different development stages (1 = young coppice, 4 = old, advanced coppice). A young coppice is characterized by low canopy cover and good light conditions whereas an old coppices allow less light to reach the understory (Manetti et al. 2016).

The historical land use classification was done based on historical images taken between 1940 – 1950 provided by the Information system for aerial photographs / LUBIS viewer (Swisstopo 2018a), e.g. aerial photographs taken on an oblique angle. The photographs of the study sites (figure 7) were then georeferenced and orthorectified with the “Monoplotting”-tool developed in 2004 by the Swiss Federal Institute for Forest, Snow and Landscape Research WSL. For the correct functioning of the tool, an aerial photograph, a digital elevation model (DEM), and several control points are needed. A mathematical model then combines the georeferenced photograph and the DEM, and relates each point, e.g. pixel, with the real world point (Bozzini, Conedera, and Krebs 2013; Conedera et al. 2013).

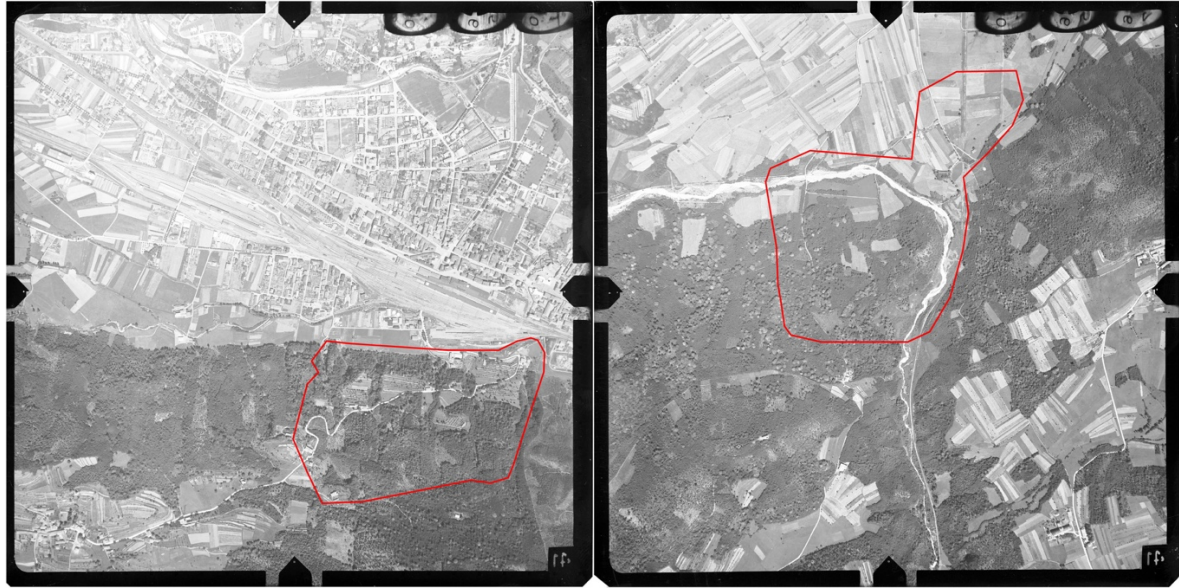


Figure 7: Aerial photographs of the two study sites taken on an oblique angle. The left image represents the study site in Chiasso, whereas the right one the one in Stabio.

Instead, the present land use classification was provided by the Swiss Map Vector 25 BETA dataset, kindly made available from the WSL, and in addition an already elaborated large-scale topographical landscape model of Switzerland (swissTLM<sup>3D</sup> 1.3) from Patrik Krebs (WSL). The datasets were then further elaborated. For example, by using the SWISSIMAGES taken during summer a further subdivision of the forests into the already explained categories (table 1) was possible.

In a further step, in order to discover if the land use management intensity drives the distribution of the black locust, an arbitrary intensity value was assigned to each land use category. A scale from 1 to 4, 1 indicating a low land use management intensity and 4 a very high management intensity was defined. In general, the higher the human impact, the higher the intensity value. Table 2 summarizes the land use categories with the assigned land use management intensity values.

Since we are also interested in the impact of the temporal change of land use management intensity on the spreading dynamics of the species, a variable that represents the temporal change of land use was computed. The variable “Evolution of land use management intensity” was calculated and resulted from the subtraction of the values of the land use management intensity of 1940 from that of the land use management intensity of 2017.

$$\textit{Evolution} = \textit{Land use intensity 2017} - \textit{land use intensity 1940} \quad (1)$$

Table 2: Land use classification categories subdivided into the 4 land use management intensity values

Land-use management intensity	Land-use classification categories
<b>1</b>	Mature coppice stage 3 Old coppice stage 4 Riparian forest City&road alleys
<b>2</b>	Young coppice stage 1 Medium coppice stage 2 Meadows and other use Agricultural area Rural road
<b>3</b>	Vineyard Vineyard with house Cultivated land areas Gardens and other uses Side roads
<b>4</b>	Main roads Railway River (with riverbank) Urban area Industrial area

#### 2.3.4 Digitalization of the distances to roads, railways, vineyards and rivers

The selected variables were chosen according to the previous consulted literature (Vítková et al. 2017; Mühletaler 2010; Cierjacks et al. 2013), expert knowledge and peculiarity found in the study sites between the two land use classification periods. For example, the upcoming of a new category, as the railways, can be seen as a new disturbance or new favourable conditions for the spread of the species.

The present railways, roads, vineyards and rivers were extrapolated from the large-scale topographical landscape model of Switzerland. Instead, the historical roads, railways, vineyards and rivers were digitalized using the georeferenced and orthorectified historical images.

The explicit documentation founded in the swissTLM<sup>3D</sup> 1.3 regarding the digitalized roads, permitted to subdivide this feature additionally in “main”, and “side” roads. Then, by comparing the historical and present land use classification it was even possible to divide the interested features into “new” and “old”. This to assess, if the disturbance caused by the construction and the presence of a road, a railway or a vineyard has a different effect on the distribution of the black locust, if the construction is more or less recent. Considering the roads and railways, the comparison and analysis of the following categories are especially interesting, because it is one of the categories which experienced the highest change over

the years. For example, during the 40 – 50s, the railway in Stabio was not even constructed, and the category “rural” roads, disappeared in the present classification.

Finally, by using the ArcGIS function “Near” (ArcGIS Pro 2018), the nearest distance from the randomized punctual data within the areas populated with black locust to the interested variables was processed. This to analyse if the distance to a specific feature has an influence on the spreading success of the species.

### 2.3.5 Digitalization of fire-, rock-fall, and landslide-events

As it has already been proven that natural disturbances favour the encroachment of the black locust, analyse this kind of disturbances is extremely important (Vítková et al. 2017; Mühletaler 2010).

To map the fire events, the database “Swissfire”, managed and developed by the WSL was consulted. The database was set up in 2005, as the WSL took the initiative, in collaboration with different cantons (UR, VS, GR and TI) to develop a forest fire database. (Pezzatti, B.; Conedera, M.; Kaltenbrunner 2005; Jud, B.A.; Frank 1996). The fire events for the different considered years, obtainable as ESRI shapefile (polygons), were selected in the database and imported in ArcGIS.

In Switzerland, a part of the SilvaProtect-CH project (SilvaProtect-CH 2016) recorded all protection forests. One part of the project consisted to model the natural hazard processes of avalanche, debris flow, rock-falls,...(Losey and Wehrli 2013). The dataset was made accessible from the WSL, and used to map the potential areas of rock fall risk. However, even if the dataset didn't indicate any area with potential risk, the areas were mapped by adopting other criteria. Areas with a slope between 30 – 50°, pending rocks and steep gradient, present a huge potential of rock fall risk (Dorren et al. 2015; Frehner, Wasser, and Schwitter 2005). Thus, according to the slope values, and the gradient lines, the rock falls were mapped. Only Chiasso presented some potential area.

The database StorMe (StorMe 2018), a natural event registry, provides the cantonal departments with a device to document natural events (Kienholz, Perret, and Schmid 2006). The interactive online map makes available information related to past natural hazard events and allows the visualization of both spatial data and detailed documentation of each event. The database was used to identify and map areas with potential landslide risk. In the study site of Chiasso, two previous events (the first in 1966 and the second in 2002) indicate potential areas, which were then digitalized with polygons in ArcGIS. Instead, in Stabio, no potential area with landslide risk was found.

## 2.4 Data elaboration

### 2.4.1 The Monte Carlo Simulation

The MCS is a resampling method which simulates many repetitions of a random event and is widely used to analyse different environmental-, as well as economic issues. The random event distribution is then compared to an observed/real event. Finally, the two distributions are evaluated statistically (Bajocco and Ricotta 2008; Conedera et al. 2011; Carmel et al. 2009). This stochastic simulation was already implemented in other studies (See Bajocco and Ricotta 2008, Conedera et al. 2011, Burkhard 2017) and proven to give accurate results. To determine the parameters having the highest influence on the encroachment of the black locust and to be able to identify if the species has a site-selective grow behaviour the MSC was thought to be appropriate.

Before run the simulation, all interested variables were subdivided into additional categories so that for the further analysis, each point could be assigned to a specific category. Table 4 and 5 gives an overview of the choice of the variables taken into consideration and the respective categories. The categories related to distance variables were defined by considering the histogram distribution of the single variables (Appendix I, Fig. 22 - 23). All the times the histogram showed a pronounced change, a category was set.

The 7 categories of the variable “Evolution of land use intensity” calculated according equation 1, ranges from negative to positive values. Zero means no change in land use intensity, negative values assess a piece of land experiencing a lower management intensity, e.g. that maybe is abandoned. Instead, positive values denotes a higher intensity.

The observed event is represented by points, which are found within the areas previously mapped with black locust. The starting idea was to calculate the centroid of each polygon encroached by the species. However, the expanded black locust populations in both study sites and consequently large polygons, would have meant an underrepresentation of it if only a centroid would have been considered. Hence, another approach was defined. To generate a point distribution within the encroached areas a series of points scattered randomly over the entire study sites were simulated. The number of points was defined by creating a regular grid (ArcGIS function “fishnet”) of 5mx5m over the entire study sites. The grid-size was approximated by taking into account the possible distance between single mature black locust trees. We supposed that a distance of 5m could be a reasonable one (Pividori M. 2003). Further, by calculating the centroid of each polygon of the grid, the number of random points was extrapolated. With the function “Create Random Points” of ArcGIS, the specific number of points was generated for each study site. Then, the random points were cut to the areas populated with black locust. This equals more to a real distribution and the problem of underrepresentation of large polygons falls away. Note that this point distribution,



even if it is randomly, represents the observed event and not the random one! This points were then utilized afterwards for the MCS (See Table 3, row 4). Figure 8 gives an example of the generated random points for Chiasso and Table 3 summarises the number of centroids and points used for the simulation.

Table 3: Number of centroids, random points and points within the area of black locust used for the simulation

Study site	Chiasso	Stabio
Nr. of centroids	15'801	34'604
Nr. of random points	15'801	34'604
Nr. of points within the area of black locust	2'567	8'422

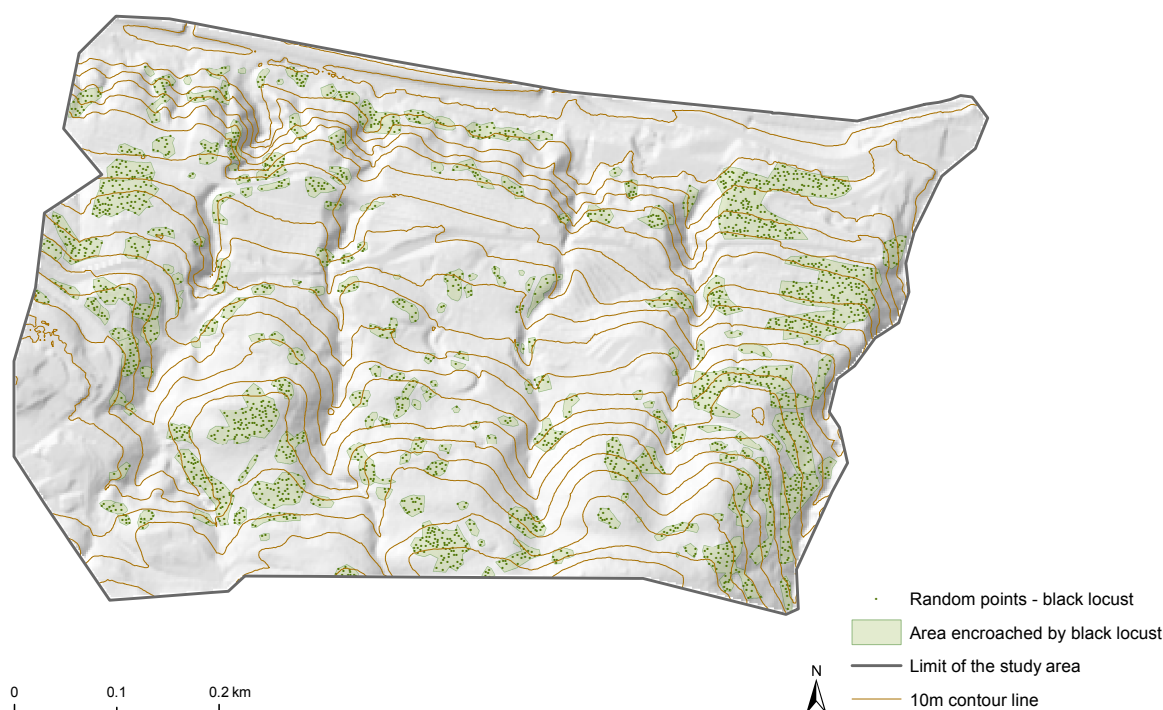


Figure 8: Example of the representation of the observed event in the MCS, e.g. the points within the area populated by black locust in the study site of Chiasso

Instead, the random distribution is simulated by generating a series of points scattered over the entire study sites randomly starting from the number of points within the areas encroached by the species. The attribution of the characteristics to these points is made according to the expected percentiles, calculated with the relative area the individual categories occupy. With each MCS and for each variable, the points are distributed randomly in the various categories and then counted. In this way, by considering the values of each simulation, a reference distribution is obtained for each variable.

The expected percentiles were calculated by counting the number of random points within each category and divided by the total number of random generated point. For the

orographic parameters the function “Extract Value by Points” allowed to extract the elevation, slope and aspect values for the single points and afterwards the same procedure as for the other variables was adopted. In general, we take the assumption that the percentage of points in the various categories for each variable can be considered as the relative area of the category. For the variable mapped with polygons in ArcGIS, the relative area was compared with the real area calculated in ArcGIS. This is the case for variables: past/present land use classification, land use management intensity, landslide, rock fall, fire events, elevation, slope, and aspect.

Finally, with the common used double-tailed statistical test, the observed and the random distribution were evaluated statistically. This to see if they are statistically different, equal or not. Basically, in the double-tailed statistical test, the critical area of a normal distribution is two-sided and it is verified if a sample is greater or less than a certain range of values.

The actual area colonized by black locust in each category was then compared with the results of 9999 random simulations and evaluated statistically. Since the MCS is dependent on the number of runs, the 9999 random simulations ensures a statistical significance of a p-value < 0.0001. Therefore, a huge strength of evidence.

Table 4: Overview of the subdivision of the variables into the different categories which will be used for the MCS

Variable	Categories
<b>Anthropogenic disturbance</b>	
<b>Land-use 1940</b>	19 categories (See table 1)
<b>Land-use 2017</b>	19 categories (See table 1)
<b>Land-use intensity 1940</b>	4 categories (See table 2)
<b>Land-use intensity 2017</b>	4 categories (See table 2)
<b>Evolution of land use intensity</b>	7 categories (-3, -2, -1, 0, 1, 2, 3)
<b>Natural disturbance</b>	
<b>Fire events</b>	2 categories (0 = no event; 1 = event)
<b>Rock falls</b>	2 categories (0 = no event; 1 = event)
<b>Landslide</b>	2 categories (0 = no event; 1 = event)
<b>Orographic variable</b>	
<b>Altitude [s.l.m.]</b>	3 categories (0 – 300, 300 – 350, 350 – 400, 400 – 450)
<b>Slope [%]</b>	4 categories (0 – 15, 15 – 30, 30 – 45, > 45)
<b>Aspect [°]</b>	3 categories (0 – 90, 90 – 180, 180 – 270, 270 – 360)

Table 5: Overview of the subdivision of the distance variables into categories which will be used for the MCS

Study site	Variable	Category
<b>Chiasso</b>	Distance from vineyards - Old vineyards - New vineyards	5 categories (0 – 10, 10 – 50, 50 – 80, 80 – 120, > 120)
	Distance from main roads - Old main roads - New main roads	5 categories (0 – 20, 20 – 50, 50 – 100, 100 – 150, > 150)
	Distance from side roads - Old side roads - New side roads	4 categories (0 – 25, 25 – 50, 50 – 100, > 100)
	Distance from railways - Old railways - New railways	5 categories (0 – 50, 50 – 200, 200 – 250, 250 – 450, > 450)
	Distances from rivers - Old rivers - New rivers	4 categories (0 – 50, 50 – 100, 100 – 200, > 200)
<b>Stabio</b>	Distance from vineyards - New vineyards	5 categories (0 – 250, 250 – 500, 500 – 700, 700 – 1000, > 1000)
	Distance from main roads - Old main roads - New main roads	4 categories (0 – 50, 100 – 150, 150 – 350, > 350)
	Distance from side roads - Old side roads - New side roads	4 categories (0 – 100, 100 – 250, 250 – 400, > 400)
	Distances from rural roads - Old rural roads	4 categories (0 – 25, 25 – 50, 50 – 100, > 100)
	Distance from railways - New railways	5 categories (0 – 50, 50 – 150, 150 – 200, 200 – 400, > 400)
	Distances from rivers - Old rivers - New rivers	5 categories (0 – 50, 50 – 100, 100 – 250, 250 – 300, > 300)

## 2.4.2 Habitat modelling suitability

### *Data preparation*

For the model generation, which explains the distribution of the black locust more in general, additionally to the data of the study site of Chiasso and Stabio, the data of the already analyzed study site of Sementina (Burkhardt 2017) were made kindly accessible. The data must be uniformed with the method utilized in the other sites. In particular, the generation of the observed distribution of black locust for the MCS needed to be revised. This because, Burkhardt (2017) utilized the centroids of each area populated with the species instead of a set of random points within these areas.

As input-dataset a matrix with all interested variables represented by points was generated. It contains all variables which are thought to have a driving force on the spread strategies and show similar results over the study sites (See table 19 in the appendix II). This is especially the case for the variable: roads, vineyards, slope, fire-events, land use management intensity, and its evolution. Variable which were not present in the study site of Sementina were assigned to zero whereas variables too far away from the site to have an influence on the presence of black locust were approximated with a distance of "999m". Overall, twenty variables and 129'447 well-dispersed points were used for the modeling.

#### *Maximum Entropy Modeling - MaxEnt*

The MaxEnt software packages is mostly used to model species niches and distributions. It is based on the maximum-entropy approach and models from presence-only species records (Elith et al. 2011; Merow, Smith, and Silander 2013; Elith and Franklin 2013). Thus, if the black locust is present or not at a specific point. The model can constructs a probability distribution over all the grid cells of an area and expresses the suitability of each cell as a function of different variables at that grid cell. The output is logistic and the probability of species distribution in the space vary from 0 to 1 (Amici et al. 2017). An elevate value at a particular grid cell means suitable conditions for the encroachment of a species (GBIF 2017). The model is also able to predict the response curve for the predictor variables, showing the progress and development of the retained variables.

A general model considering the data of the three study sites was generated, and another that considered the amount of points within the areas encroached with black locust as well. Then, a single model for every study site was also constructed. However, due to overfitting reasons, we decided to not consider it. In fact, the model for the single sites would hardly be appropriate for other sites. Finally, we decided to only consider the general model and not the one with the areas encroached by the species. This because their results excluded some variables which are thought to have a huge driving force on the colonization dynamics of the species, e.g. fire events and rock fall areas.

To evaluate the model performance, the AUC (Area Under the Curve), an independent threshold was adopted. This threshold measures the ability of the model to discriminate between presence and absence data based on the predictor variables. Values usually ranges between 0.5 – 1, one indicating a high model performance (West et al. 2016; Sharma et al. 2018). Figure 9 gives an illustration of how AUC works.

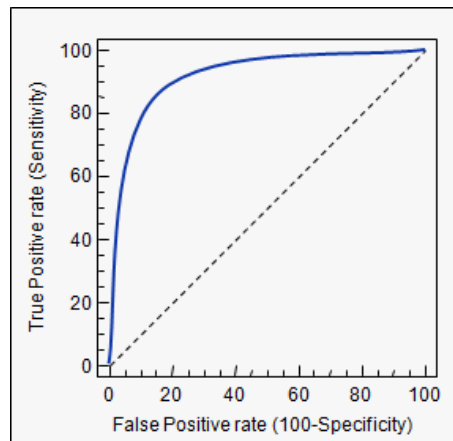


Figure 9: Representation of the AUC. The true positive rate corresponds to the proportion of positive data points, e.g. presence of black locust that are correctly considered as positive. The higher it is, the better the model. Instead the false positive rate indicates the proportion of negative data points, e.g. absence of black locust, that are mistakenly considered as positive. The higher the value, the more negative data will be misclassified. The dashed line indicate an AUC value of 0.5 (Stack Exchange 2018).

To validate the model, a cross-validation is a widely utilized confident method. Part of the input data is not used for the model generation, but used to test the model performance. If the validation show positive results, the model can then be finalized (Merow, Smith, and Silander 2013). We didn't undertake this validation due to complexity reasons. However, after generating the model, we compared the results with the real presence of black locust mapped previously and built boxplots to see if the model is able to discriminate the species presence and absence. Then, with a non-parametric Wilcoxon Test (rank sum) for independent sample, we evaluated if the presence and absence of the species were significantly different or not.

Since the input-data is represented by points, the result of the modelling will be represented by points as well. Each point will be assigned to a MaxEnt value, e.g. a number between 0 and 1. Then to generate the probability maps an interpolation was adopted. The probability distribution starting from points, was constructed in ArcGIS by adopting an Inverse Distance Weighted (IDW) interpolation. According to IDW, things that are close to each other are more similar than farther one. The algorithm assumes that the local influence of points diminished with distance. Therefore, points which are closest to the prediction location are assigned with greater weights. These weights then diminish as a function of distance (ArcGIS Pro 2018a).

### 3. Results

#### 3.1 Distribution of the black locust in the study sites

Figure 10 shows the mapped distribution of the black locust in the study sites. Even if the distribution is difficult to explain and it's hard to see a general pattern, Stabio presents expanded black locust populations whereas Chiasso different hotspots. Overall, 11.8% of the study site of Chiasso and 27% of the study site of Stabio were mapped with black locust.



Figure 10: Study sites of Chiasso and Stabio with the area populated with black locust, represented in light-yellow

## 3.2 Orographic parameters

### 3.2.1 Altitude

Table 6 shows the result of the MCS in relation to the altitude values. It should be noted that the altitude ranging from 0 – 300m a.s.l. in the study site of Stabio, didn't present any result. This because no random point presented such altitude value. Therefore, for this category, the MCS was not able to give results.

For both study sites, the lowest altitudinal belt (lower than 350m a.s.l.) significantly underrepresent the black locust, whereas altitude greater than 350m a.s.l. significantly overrepresent it. In Stabio, either altitudes greater than 400m a.s.l. show a positive correlation which is not the case in Chiasso.

Table 6: Frequency of black locust in relation to the altitude [m a.s.l.]

<b>Chiasso</b>	<b>Value</b>	<b>0 - 300</b>	<b>300 - 350</b>	<b>350 - 400</b>	<b>400 - 450</b>
	True value	29.68	24.43	36.74	9.15
	Max.	35.76	29.84	32.72	13.95
	Min.	28.98	22.67	26.18	8.88
	Mean	32.21	26.68	29.74	11.38
	Significance	---	--	+++	--

<b>Stabio</b>	<b>Value</b>	<b>0 - 300</b>	<b>300 - 350</b>	<b>350 - 400</b>	<b>400 - 450</b>
	True value	-	2.16	74.66	23.18
	Max.	-	15.15	76.98	12.25
	Min.	-	12.30	73.53	9.74
	Mean	-	13.70	75.29	11.02
	Significance	-	--	n.s.	+++

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/-- =  $p < 0.0001$ ; ++/-- =  $p < 0.01$ ; +/- =  $p < 0.05$ ; n.s.= not significant

### 3.2.2 Slope

The results of the MCS (table 7) in relation to the slope shows that, compared to a randomized distribution, in both study sites, the black locust is significantly overrepresented in areas with slope values between 30 – 45%. Even slope values between 15 – 30% favours the black locust in Stabio, whereas this values are not significant in Chiasso. Despite, slope values greater than 45% are not significant in both study sites, slope values below 15% show a negative correlation and significantly underrepresent the black locust.

Table 7: Frequency of black locust in relation to the slope [%]

<b>Chiasso</b>	<b>Value</b>	<b>0 - 15</b>	<b>15 - 30</b>	<b>30 - 45</b>	<b>&gt; 45</b>
	True value	13.42	34.36	46.15	6.07
	Max.	28.75	38.49	36.89	8.45
	Min.	22.20	31.16	29.84	4.40
	Mean	25.36	34.88	33.30	6.46
	Significance	---	n.s.	+++	n.s.

<b>Stabio</b>	<b>Value</b>	<b>0 - 15</b>	<b>15 - 30</b>	<b>30 - 45</b>	<b>&gt; 45</b>
	True value	70.84	25.39	3.78	0.00
	Max.	83.26	17.18	3.31	0.06
	Min.	80.09	14.12	1.94	0.00
	Mean	81.78	15.57	2.64	0.01
	Significance	---	+++	+++	n.s.

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- =  $p < 0.0001$ ; ++/-- =  $p < 0.01$ ; +/- =  $p < 0.05$ ; n.s.= not significant

### 3.2.3 Aspect

In both study sites, the black locust show a significant positive correlation with areas exposed to north-east (table 8). Despite, a clear negative correlation can be observed for aspect values ranging between 180 – 270°, namely southwest.

On the other hand, all other aspect values in the study site of Chiasso shows a negative or even not significant correlation. In the study site of Stabio, the black locust is significantly underrepresented in areas exposed from east to west and significantly overrepresented even in areas exposed to the northwest. Contrary, in the study site of Chiasso, areas exposed to the northwest are negatively correlated with the black locust.

Table 8: Frequency of black locust in relation to the aspect [°]

<b>Chiasso</b>	<b>Value</b>	<b>0 - 90</b>	<b>90 - 180</b>	<b>180 - 270</b>	<b>270 - 360</b>
	True value	58.82	8.92	6.31	25.94
	Max.	56.41	11.88	9.93	33.15
	Min.	49.08	7.60	5.96	26.18
	Mean	52.78	9.72	7.97	29.54
	Significance	+++	n.s	---	---

<b>Stabio</b>	<b>Value</b>	<b>0 - 90</b>	<b>90 - 180</b>	<b>180 - 270</b>	<b>270 - 360</b>
	True value	41.15	17.94	11.84	29.07
	Max.	35.15	29.79	17.34	24.98
	Min.	30.86	26.25	14.41	21.42
	Mean	32.93	28.06	15.82	23.19
	Significance	+++	---	---	+++

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- =  $p < 0.0001$ ; ++/-- =  $p < 0.01$ ; +/- =  $p < 0.05$ ; n.s.= not significant



### 3.3 Anthropogenic disturbance

#### 3.3.1 Land use change, management intensity and evolution

##### *Land use change*

Table 11 represent the results of the influence of the land use change on the presence of the black locust in the two study sites whereas figure 11 provides a visual result of the land use classification for the two different periods. It should be noted that a few land use categories are not present in both study sites, e.g. industrial- , agricultural area or vineyard with house. Instead, some only appear in the present classification or disappear completely through the years, e.g. garden and other uses or city&road alleys.

The categories “vineyard”, “river”, “young”-, “medium”- and “old coppice” of the land use classification of 1940 in Chiasso didn’t show significant correlations whereas the category “medium-“ and “mature coppice” significantly overrepresent the black locust. In all other categories the black locust is significantly underrepresented. The study site in Stabio show pretty similar results.

In both study sites, during 2017, the black locust is significantly overrepresented in the current medium, mature and in Stabio even the old coppices. Most of these areas coincide with those where in 1940 were coppices at a lower stage. In all other land use categories in 2017 the black locust is significantly underrepresented, except in the categories “city&road alleys” in Stabio, where there are not significant correlations. Both study sites show a slightly lower influence on the black locust in the category “riparian forest”.

##### *Land use management intensity*

Table 9 show the results of the land use management intensity influence on the encroachment success of the black locust. For both study sites, a low management intensity value favours significantly the come up of the black locust. This, in both year. In all other categories, a higher land use management intensity, disfavour the presence of black locust. In general, the two study sites show a quite similar behaviour. However, even a slightly higher land use management intensity value in Chiasso in 2017 seems to even favour the black locust. This is not the case in Stabio.

##### *Land use management intensity evolution*

Table 10 shows the results of the temporal land use management intensity evolution on the colonization of the black locust in the two study sites. For both study sites, it appears that the black locust is significantly underrepresented where the management intensity increased through the years whereas the spread of the black locust is significantly favoured where the management intensity hasn’t changed or even decreased through the years.

Analysing the general trend of the temporal evolution of the land use management intensity, it emerges that the two study sites show quite similar results. Only for the study site in Stabio, a slightly lower temporal land use management intensity evolution (value -1) significantly disfavours the presence of the black locust.

Table 9: Frequency of black locust in relation to the land use management intensity

<b>CHIASSO</b>		<b>VALUE</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>1940</b>	True value		64.39	16.40	18.11	1.09
	Max.		62.60	18.43	24.97	5.73
	Min.		54.89	12.74	18.35	2.73
	Mean		58.54	15.52	21.77	4.17
	Significance		+++	n.s.	---	---
<b>2017</b>	True value		78.38	18.00	2.10	1.52
	Max.		62.25	15.35	19.59	14.41
	Min.		54.97	10.13	13.91	9.27
	Mean		58.78	12.60	16.71	11.92
	Significance		+++	+++	---	---

<b>STABIO</b>		<b>VALUE</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>1940</b>	True value		76.29	9.37	12.01	2.33
	Max.		47.03	14.58	41.12	4.35
	Min.		42.47	12.05	12.05	2.87
	Mean		44.67	13.27	39.11	3.53
	Significance		+++	---	---	---
<b>2017</b>	True value		91.07	8.18	0.27	0.47
	Max.		52.71	31.67	13.38	9.31
	Min.		48.49	27.76	10.57	6.90
	Mean		50.79	29.84	11.85	8.08
	Significance		+++	---	---	---

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- =  $p < 0.0001$ ; ++/-- =  $p < 0.01$ ; +/- =  $p < 0.05$ ; n.s. = not significant

Table 10: Frequency of black locust in relation to the evolution of land use management intensity

<b>CHIASSO</b>		<b>VALUE</b>	<b>-3</b>	<b>-2</b>	<b>-1</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>
	True value		0.47	9.19	23.02	57.07	7.75	1.56	0.93
	Max.		0.74	5.49	18.19	63.50	13.25	7.52	5.77
	Min.		0.00	2.57	12.93	56.14	8.53	4.01	2.65
	Mean		0.29	3.94	15.53	59.67	10.72	5.71	4.14
	Significance		n.s.	+++	+++	-	---	---	---

<b>STABIO</b>		<b>VALUE</b>	<b>-3</b>	<b>-2</b>	<b>-1</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>
	True value		0.40	11.30	10.14	75.32	2.26	0.27	0.31
	Max.		0.81	8.95	27.57	56.64	9.42	3.43	2.26
	Min.		0.26	6.72	23.64	52.09	7.14	2.13	1.14
	Mean		0.51	25.49	25.49	54.07	8.28	2.73	1.60
	Significance		n.s.	+++	---	+++	---	---	---

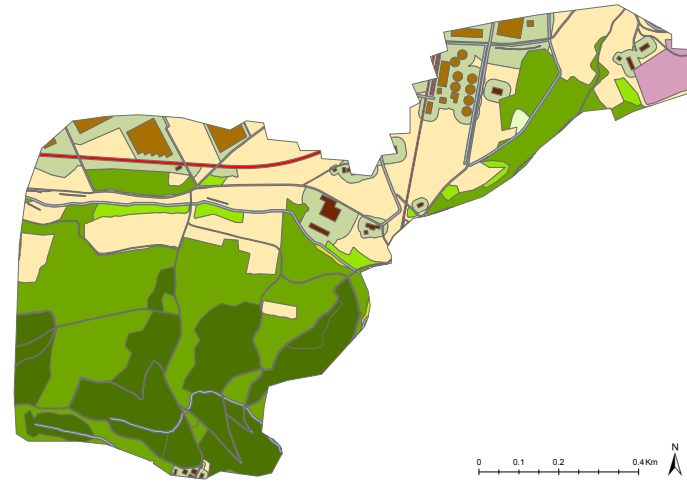
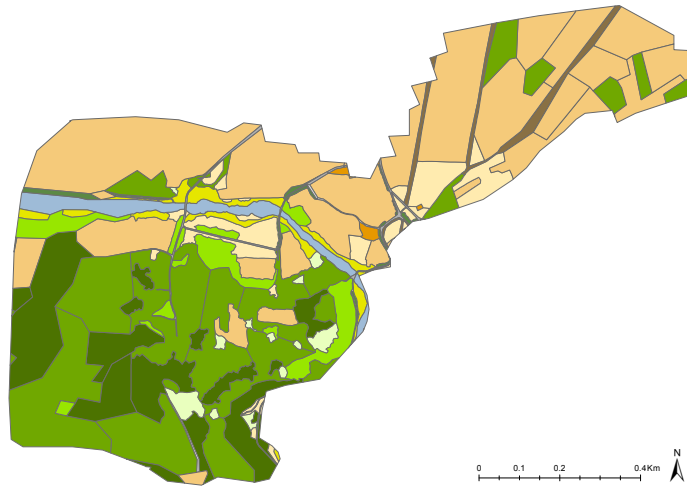
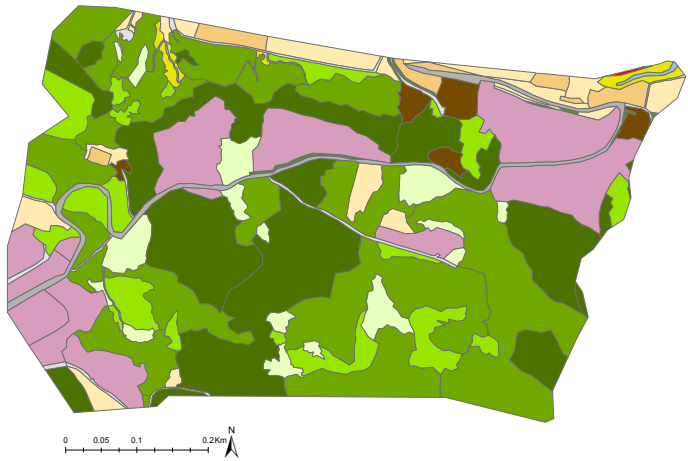
True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- =  $p < 0.0001$ ; ++/-- =  $p < 0.01$ ; +/- =  $p < 0.05$ ; n.s. = not significant

Chiasso

Stabio



- Vineyard with house
- Vineyard
- Agricultural area
- Meadows and other uses
- Urban area
- Railway
- Young coppice
- Medium coppice
- Mature coppice
- Old coppice
- Riparian forest
- River
- Garden and other uses
- Industrial area
- Cultivated land area
- Main road
- Secondary road
- City and road alley
- Rural road

Figure 11: Land use change classification of the two study sites for the two interested year, 1940 and 2017. The upper images stands for the historical land use classification whereas the lower one for the present.

Table 11: Frequency of black locust in relation to the land use classification for the study sites of Chiasso and Stabio

		VINEYARD WITH HOUSE	VINEYARD	AGRICULTURAL AREA	MEADOWS AND OTHER USES	URBAN AREA	CULTIVATED LAND AREA	MAIN ROAD	SECONDARY ROAD	CITY&ROAD ALLEY	RIPARIAN FOREST	RIVER	RAILWAY	YOUNG COPPICE	MEDIUM COPPICE	MATURE COPPICE	OLD COPPICE	GARDENS AND OTHE USES	INDUSTRIAL AREA	RURAL ROAD	
<b>CHIASSO</b>		<b>VALUE</b>																			
<b>1940</b>	True value		17.49		0.55	0.12	0.12	0.66	0.08	0.00	0.08	0.31	0.00	3.74	29.07	38.84	25.48				
	Max.		20.14		7.28	2.92	0.04	3.16	2.10	0.97	1.36	0.66	0.12	4.91	10.28	36.31	28.28				
	Min.		14.37		3.93	0.97	2.88	1.05	0.43	0.00	0.19	0.00	0.00	2.14	6.31	28.98	21.08				
	Mean		17.07		5.56	1.75	1.75	2.03	1.17	0.37	0.70	0.25	0.01	3.46	8.29	32.67	24.79				
	Significance		n.s.		---		---	---	---	---	-	n.s.		n.s.	n.s.	+++	n.s				
<b>2017</b>	True value	0.00	0.23		2.96	0.23		0.00	0.00			1.29	0.00		15.04	53.80	24.58	1.87			
	Max.	1.21	6.39		8.84	5.03		6.27	2.42			4.87	1.56		7.71	39.77	25.71	11.96			
	Min.	0.08	3.47		5.03	2.10		3.19	0.58			1.87	0.23		4.29	32.53	19.48	7.71			
	Mean	0.55	4.76		6.65	3.39		4.56	1.44			3.16	0.82		5.95	36.08	22.69	9.94			
	Significance	---	---		---	---		---	---			---	---		+++	+++	+	---			
<b>STABIO</b>																					
<b>1940</b>	True value			0.00	2.64		11.97	0.19	0.04	0.17	1.94	2.14		1.74	4.90	47.24	26.95			0.09	
	Max.			0.49	6.14		40.99	0.95	0.44	1.12	2.97	3.81		1.97	5.60	30.59	14.76			2.14	
	Min.			0.06	4.32		36.86	0.33	0.05	0.39	1.66	2.18		1.04	3.87	26.45	12.03			1.13	
	Mean			0.24	5.24		38.89	0.63	0.22	0.72	2.28	2.90		1.47	4.71	28.27	13.40			1.60	
	Significance			---	---		---	---	---	---	-	n.s.		n.s.	n.s.	+++	n.s.			---	
<b>2017</b>	True value	1.66			4.65	0.00		0.25	0.11	0.08	0.02	0.22	0.22	0.00	3.53	59.52	31.45	0.17	0.00		
	Max.	2.24			29.46	0.90		2.99	1.03	0.24	0.30	2.45	1.22	0.42	2.64	32.64	21.68	10.81	3.13		
	Min.	1.18			25.45	0.30		1.79	0.39	0.00	0.00	1.35	0.45	0.45	1.48	28.83	28.83	8.38	1.84		
	Mean	1.67			27.61	0.57		2.39	0.67	0.09	0.12	1.90	0.80	0.80	2.02	30.62	30.62	9.51	2.43		
	Significance	---			---	---		---	---	n.s.	--	---	---	---	---	+++	+++	+++	---	---	

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/-- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s.= not significant

### 3.3.2 Presence and distance from different selected variables

#### *Distances from different types of roads*

Since the variable new and old main roads didn't show important correlations, the results can be found in the appendix II on table 18. The same applies for the variable "old rural roads" of Stabio. Important is to state that the "old and new main roads" only showed an overrepresentation of black locust at a distance greater than 50m in both study sites. Smaller distances underrepresent the black locust.

Instead, the "new and old side roads" show some interesting results (table 12). Although in Chiasso only distances between 50 – 100m from the old side roads overrepresent the black locust, in Stabio the situation is different. In fact, the "new side roads" shows an overrepresentation of black locust in the first 100m, which is not the case for any other road variable. Many of the other categories show a strong negative correlation with black locust populations.

#### *Distances from railways*

In both study sites, distances between 0 – 50m from the railways significantly underrepresent black locust populations (table 13). Instead, in the study site of Chiasso, distances between 50 – 200m favors significantly the frequency of black locust. That's not the case in Stabio. Here only in greater distances (200m) the black locust is significantly overrepresented. In all other categories, the black locust is either significantly underrepresented or show no significant correlation.

#### *Distances from vineyards*

Table 14 show the results of the frequency of black locust in relation to distances from the "old and new vineyards" for the study site of Chiasso. The result of the study site of Stabio were not included in table 14, because it didn't show any significant correlation. Probably, this is due to the one only vineyard present in the study site, which distance from the area populated with black locust is too high to probably have an influence on their distribution.

Contrary to what we hypothesized, black locust is significantly underrepresented in small distances from the vineyards and overrepresented in distances greater than 50m. In a few categories, the results show no significant correlation.

#### *Distances from rivers*

By relating the frequency of black locust with their distance from rivers, unfortunately, there are little significant correlations (table 15).

In both study sites, only distances greater than 100m from the river significantly overrepresent the black locust, whereas most of the other categories correlates negatively or didn't show any significant correlation. Nevertheless in Chiasso, still distances of 50m influence positively the frequency of black locust.

Table 12: Frequency of black locust in relation to distances from the old and new side roads in the two study sites

		<b>Value</b>	<b>0 - 100</b>	<b>100 - 250</b>	<b>250 - 400</b>	<b>&gt; 400</b>	
		<b>Stabio</b>	<b>Old side roads</b>	True value	19.60	53.63	18.86
Max	31.85			44.44	16.28	14.87	
Min	27.71			40.57	13.24	11.96	
Mean	29.44			42.61	14.57	13.37	
Significance	---			+++	+++	---	
<b>New side roads</b>	True value		60.38	33.00	6.57	0.06	
	Max		49.31	35.36	16.75	5.06	
	Min		44.66	31.12	13.80	3.23	
	Mean		47.11	33.33	15.32	4.24	
	Significance		+++	n.s.	---	---	
<b>Chiasso</b>	<b>Old side roads</b>	<b>Value</b>	<b>0 - 25</b>	<b>25 - 50</b>	<b>50 - 100</b>	<b>100 - 150</b>	<b>&gt; 150</b>
		True value	11.30	15.97	36.31	23.69	23.66
		Max	25.75	22.48	38.14	18.66	9.93
		Min	19.75	16.48	30.50	13.05	5.84
		Mean	22.52	19.20	34.63	15.78	7.87
	Significance	---	---	++	+++	+++	
	<b>New side roads</b>	True value	23.22	20.76	20.57	18.97	16.48
		Max	27.54	20.92	27.27	18.70	20.37
		Min	20.96	15.23	20.92	13.25	14.84
		Mean	24.11	18.23	24.34	15.70	17.61
Significance		n.s.	---	---	++	n.s.	

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/-- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s. = not significant

Table 13: Frequency of black locust in relation to the distance from the railway

		<b>Value</b>	<b>0 - 50</b>	<b>50 - 200</b>	<b>200 - 250</b>	<b>250 - 450</b>	<b>&gt; 450</b>
		<b>Chiasso</b>	<b>Old railway</b>	True value	0.00	15.50	4.67
Max	2.69			11.38	6.00	30.35	61.12
Min	0.86			7.17	3.00	23.61	54.07
Mean	1.70			9.28	4.40	26.91	57.71
Significance	---			+++	---	n.s.	n.s.
<b>New railway</b>	<b>Value</b>		<b>0 - 50</b>	<b>50 - 200</b>	<b>200 - 250</b>	<b>250 - 450</b>	<b>&gt; 450</b>
	True value		5.38	35.80	8.18	45.23	5.41
	Max		13.91	34.24	12.23	42.62	10.17
	Min		9.27	27.31	7.56	35.80	6.19
	Mean		11.50	31.14	9.89	39.34	8.13
Significance	---	+++	---	+++	--		
<b>Stabio</b>	<b>New railway</b>	<b>Value</b>	<b>0 - 50</b>	<b>50 - 150</b>	<b>150 - 200</b>	<b>200 - 400</b>	<b>&gt; 400</b>
		True value	0.81	7.36	2.02	41.33	48.48
		Max	14.21	21.93	9.24	30.04	32.55
		Min	11.66	18.48	6.91	26.35	28.86
		Mean	12.97	20.13	7.99	28.16	30.75
Significance	---	---	---	+++	+++		

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/-- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s. = not significant

Table 14: Frequency of black locust in relation to distances from old and new vineyards for the study site of Chiasso

Chiasso	Old vineyards	Value	0 - 10	10 - 50	50 - 80	80 - 120	120 - 150	> 150
		True value	23.26	21.58	15.93	17.88	6.27	15.08
Max	27.62	29.96	18.04	17.34	9.47	14.10		
Min	21.70	22.79	12.62	12.43	5.61	9.08		
Mean	24.52	26.71	15.30	14.70	7.44	11.33		
Significance	n.s.	---	n.s.	+++	--	+++		
Chiasso	New vineyards	Value	0 - 10	10 - 50	50 - 80	80 - 120	120 - 150	> 150
		True value	2.65	18.82	22.87	19.98	6.82	28.87
Max	10.91	22.17	18.27	23.88	14.22	26.61		
Min	6.58	16.67	13.05	18.19	9.15	19.91		
Mean	8.99	19.28	15.72	20.91	11.73	23.38		
Significance	---	n.s.	+++	n.s.	---	+++		

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s.= not significant

Table 15: Frequency of black locust in relation to distances from the old and new rivers

Chiasso	Old river	Value	0 - 50	50 - 100	100 - 200	200 - 400	> 400
		True value	12.74	15.86	34.63	31.55	5.22
Max	17.45	20.88	37.13	32.61	6.74		
Min	11.53	15.15	30.46	25.01	3.39		
Mean	14.37	17.91	33.91	28.89	4.92		
Significance	--	---	n.s.	+++	n.s.		
Chiasso	New river	Value	0 - 50	50 - 100	100 - 200	200 - 400	> 400
		True value	55.32	37.94	6.74		
Max	59.72	37.28	12.08				
Min	52.40	30.54	7.67				
Mean	56.06	34.10	9.84				
Significance	n.s.	+++	---				
Stabio	Old river	Value	0 - 50	50 - 100	100 - 250	250 - 300	> 300
		True value	8.38	4.55	29.42	6.82	50.83
Max	15.59	12.22	26.56	6.33	46.82		
Min	12.55	9.55	22.92	4.51	42.60		
Mean	14.14	10.95	24.84	5.45	44.62		
Significance	---	---	+++	+++	+++		
Stabio	New river	Value	0 - 50	50 - 100	100 - 250	250 - 300	> 300
		True value	24.69	19.76	53.61	1.95	
Max	34.11	26.18	44.36	1.80			
Min	30.19	22.56	39.95	0.88			
Mean	32.21	24.45	42.02	1.31			
Significance	---	---	+++	+++			

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s.= not significant

### 3.4 Natural disturbances

#### 3.4.1 Fire events

In the past, only a few areas were affected by fire events in the study site of Chiasso. Unfortunately, a careful analysis of the past fire events founded in the database “Swissfire” didn’t show any event for the study site in Stabio. Figure 12 show the affected fire areas in the study site of Chiasso. Overall, the area affected by fire covers 12’785.53 m<sup>2</sup>, 2.8% of the entire study site.

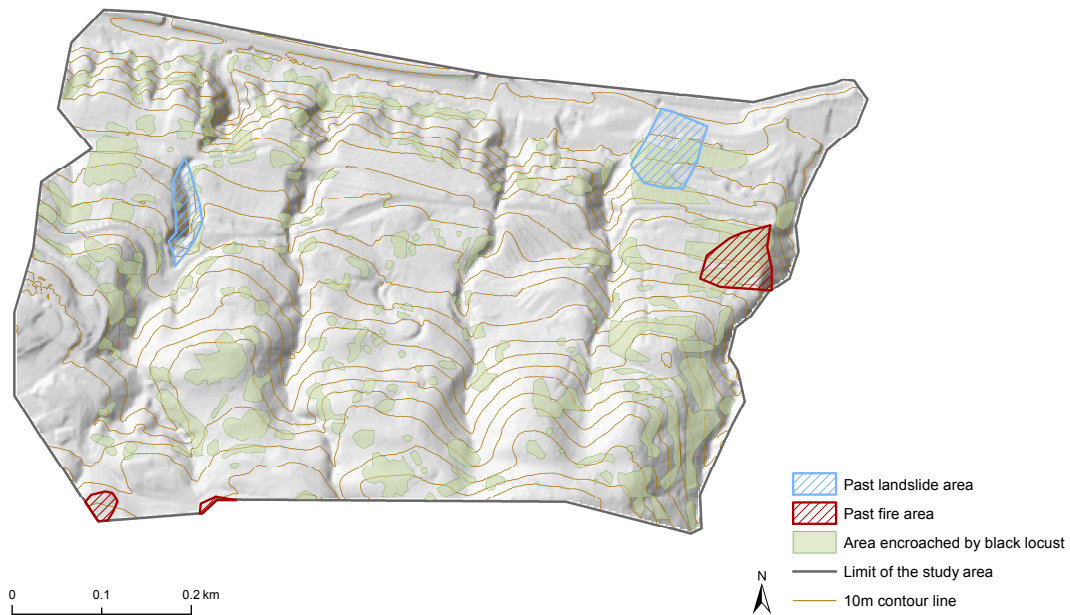


Figure 12: Area of the study site of Chiasso affected by post fire- and landslide events

The results of the influence of fire on the presence of the black locust can be seen in table 16. A clear positive correlation can be observed between the areas affected by past fires events and the frequency of the black locust. The black locust is significantly overrepresented in the area affected by past fire events and significantly underrepresented in the one never affected by fires.

Table 16: Frequency of black locust in relation the areas with past fire-events. 0 = area without fire, 1= area affected by past fire events

	Fire events		Rock fall		Landslide	
	0	1	0	1	0	1
<b>True value</b>	95.13619	4.863813	91.82	8.18	95.99	4.01
<b>Max</b>	99.53	2.26	94.08	9.78	99.14	3.08
<b>Min</b>	97.74	0.47	90.22	5.92	96.92	0.86
<b>Mean</b>	98.80	0.47	7.85	7.85	98.12	1.88
<b>Significance</b>	---	+++	n.s	n.s	---	+++

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/--- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s. = not significant



### 3.4.2 Rock fall

According to the criteria defined in the method section 2.3.5, in the study site of Chiasso a few areas with potential rock fall risk were mapped. Overall, the potential regions cover an area of about 31'622.02 m<sup>2</sup>, 6.9% of the entire study site (figure 13). Due to the very smooth slopes and the gradient lines of the study site of Stabio, no potential rock fall areas were assumed to be possible and therefore no potential area of risk was mapped.



Figure 13: Potential area of the study site of Chiasso affected by rock fall risk

Table 16 show the results of the MCS of the rock fall influence on the presence of the black locust in the study site of Chiasso. Even if we had expected a positive correlation with the potential area of rock fall risk, the results show no significant correlation.

### 3.4.3 Landslide

Figure 12 show the areas affected by past landslide events in the study site of Chiasso, mapped according to the database StorMe. According to the database, only two landslide events (1966 and 2002) were mapped, overall covering an area of 7'372.18 m<sup>2</sup>, 1.6% of the entire study site. Even for this variable of natural disturbance, the smooth slopes of the study site of Stabio and the consulting of the StorMe database, didn't show any area with potential landslide risk. Therefore, no areas were mapped.

From table 16 it results that the black locust is significantly overrepresented in the areas affected by past landslides events and underrepresented where any landslides was mapped.

### 3.5 Model generation

Figure 14 show the results of the MaxEnt modelling of the general model considering the data of all study sites in form of response curve for each predictor variables. This figure highlights the relative influence of each of the selected predictor variables. The AUC of the general model equals to 0.89 whereas the one for the single site models are shown in table 17. Equation 2 summarize the results of the general model with the best AUC:

$$\text{Black locust} \sim \text{Dist. to new and old vineyards} + \text{Dist. to new and old side/main roads} + \text{Dist. to new rivers} + \text{Dist. to old railways} + \text{Slope} + \text{Land use intensity 1940 and 2017} + \text{Land use intensity evolution} + \text{Rock fall} + \text{Fire} \quad (2)$$

The variables related to distances show a quite similar pattern, namely an increase in the predicted value of the presence of black locust after the first 20 – 50m and a continuous decrease with increasing distance. Variables, such as the slope and post fire areas show a quite distinct spike whereas variables related to the land use intensity and evolution show similar results as for the one obtained with the MCS. Compared to the results of the MCS, the evolution of land use intensity show that even for areas experiencing a higher management intensity, the predicted value increases as well.

Table 17: Summary of the AUC values for the MaxEnt model result

Site	Name	Number of points	AUC
All	General	129'447	0.89
1	Chiasso	15'801	0.84
2	Stabio	34'604	0.89
3	Sementina	79'042	0.89

Instead, figure 15 show the general MaxEnt model results as a probability distribution for each study site. A value near 1 means that the species has a huge probability to be found at the specific grid cell. In most of the cases, the areas with the highest predicted value overlap with the coppices at the medium and mature stage, the past fire areas or riparian forest. Hardly never with the vineyards, industrial- or urban areas. A general pattern consists in an lower probability in proximity to side-, main roads, rivers and even vineyards.

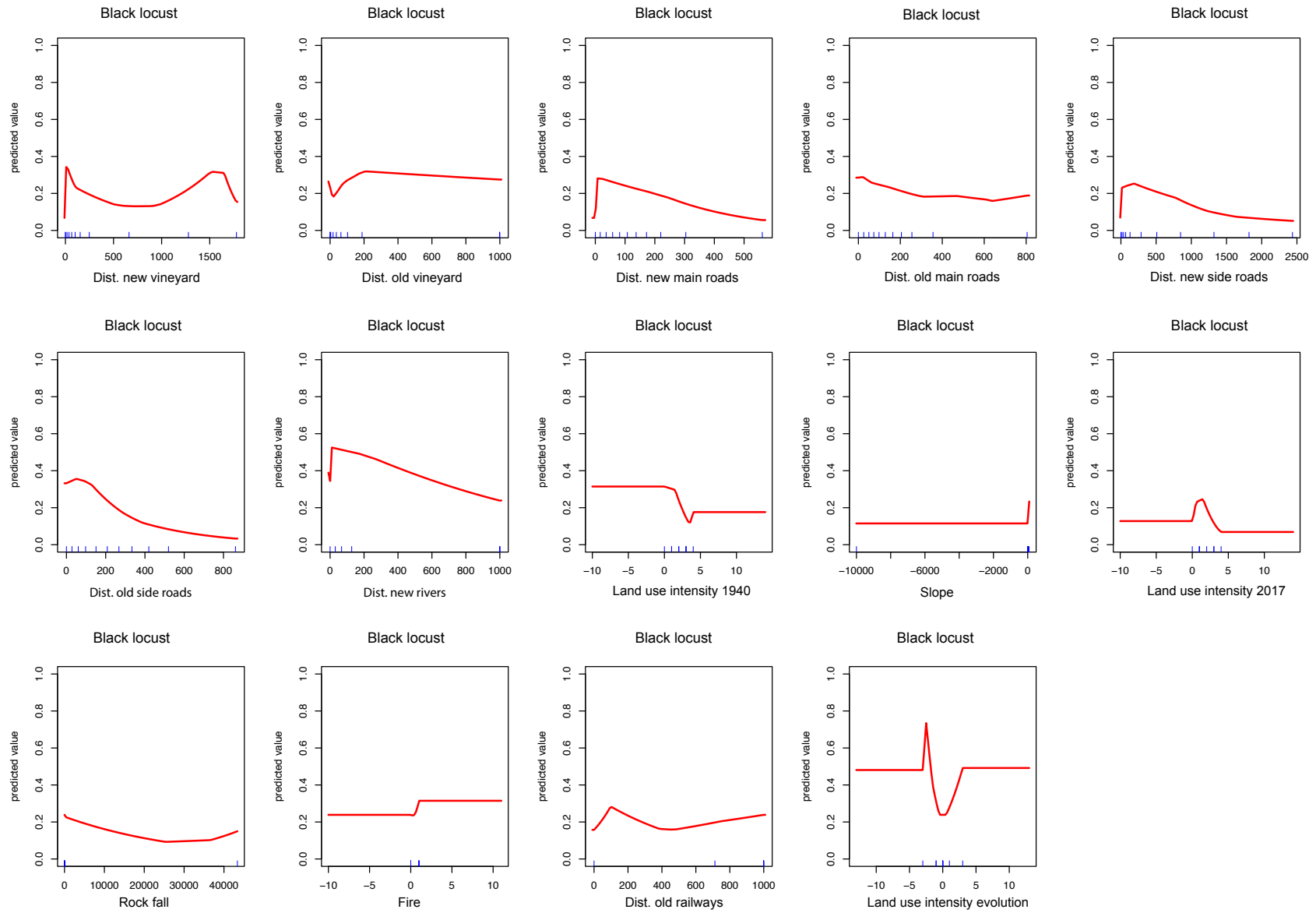


Figure 14: Predicted values for the retained variables in the general MaxEnt model with the best AUC

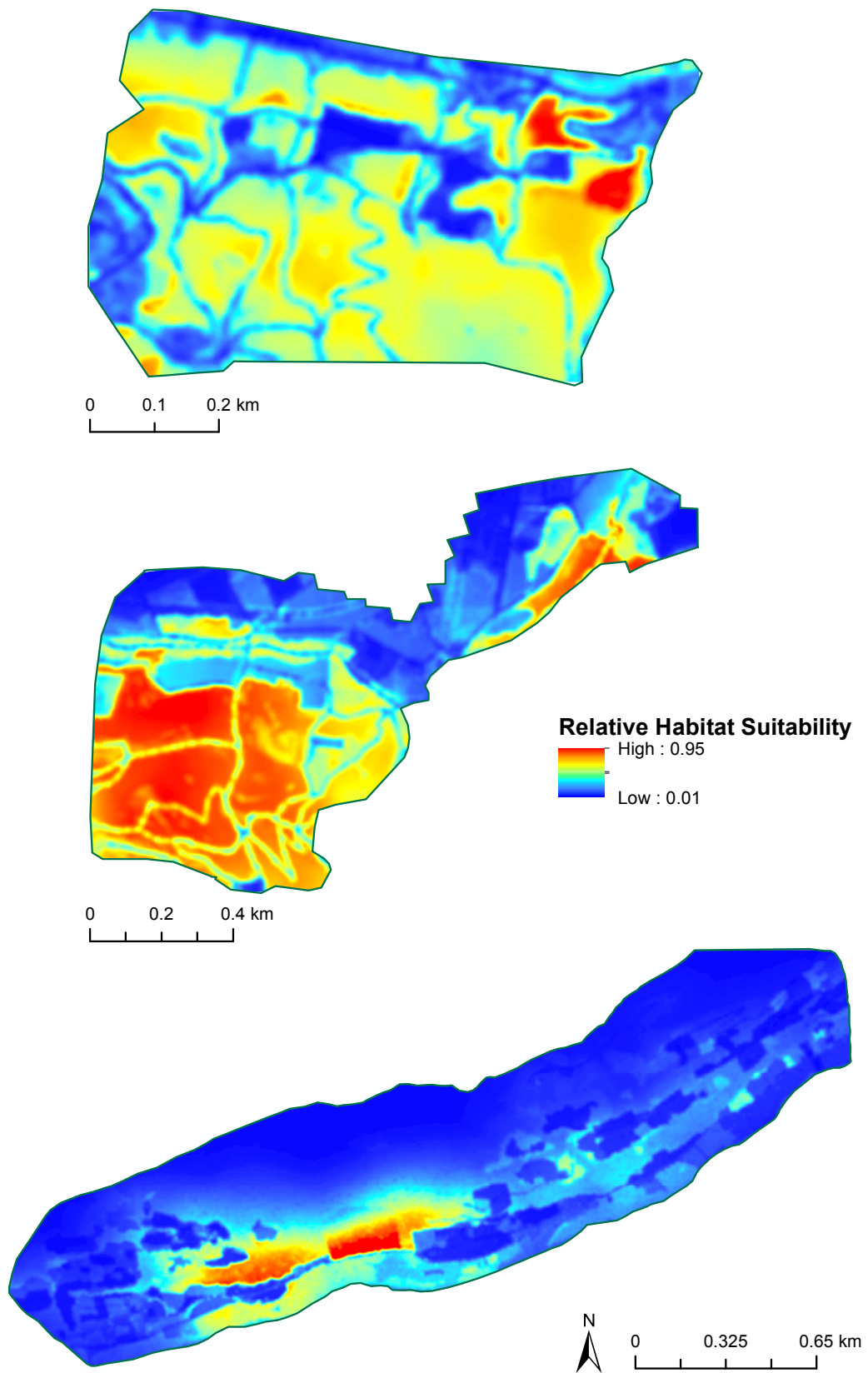


Figure 15: Probability distribution of the MaxEnt general model results with the best AUC. A high value indicates a high probability to find the species.

## 4. Discussion

### 4.1 The influence of anthropogenic disturbances

#### 4.1.1 Land use change, soil management intensity and its evolution

Many of the land use categories analysed were not significant for the distribution and the presence of the black locust. Only the medium-, mature and sometimes old coppice overrepresent the species. We would have expected that especially young coppice stands are particularly significant. Although these areas are characterized by potentially favourable light conditions, it is surprising that the correlations in both study sites are not significant. In contrast, in the few young coppice stands in Stabio, the species is even underrepresented. Maybe, considering the relative small areas, larger one would have been able to give more significant results. Observing the other coppice stages, most of the medium coppices currently corresponds to the more closed and less luminous mature coppices. Probably, the black locust benefitted from this medium stage in the past and was favoured by the relatively good light conditions. Further, in Chiasso, we can note a lower significance in the older coppice stands. This maybe can be explained by the loss of productivity of the coppice stands or with the increased competitiveness of more shade-tolerant species, which decreases the occurrence of the species (Vítková et al. 2017; Pividori M. 2003).

By considering the land use classification and the assignment of each category to a management intensity value, the correlation with the presence of the species becomes clearer. Areas with lower human impacts such as most coppice stages, meadows and other uses promote the species significantly. On the other hand, the areas with a higher intensity value, such as urban- and industrial areas are regularly treated or cleaned and do not allow the aggressive growth of the species. This results are mostly confirmed by the response curves of the general MaxEnt model for the land use intensity management of 1940 (figure 16A) but not for the one of 2017 (figure 16B). The initial peak indicates that a slightly higher land use intensity can represent favourable conditions for the entrance of the species.

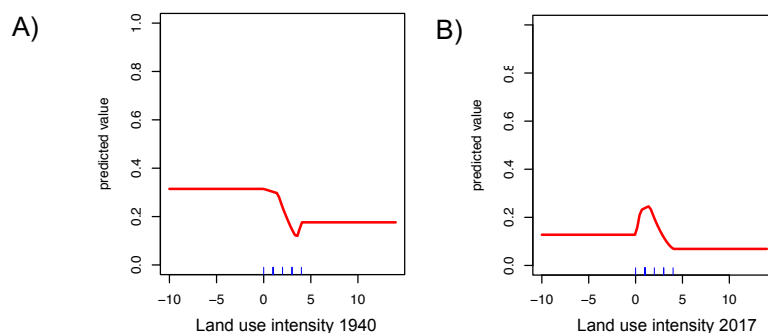


Figure 16: Response curves for the predictor variable of the land use management intensity of 1940 and 2017

The temporal comparison of the evolution of land use management intensity, allowed to discover the change that the land nowadays encroached by the black locust has undergone over time. The species tends to colonize areas that goes towards a lower management intensity, areas that became abandoned as for example vineyards or areas that slowly overgrows with bushes. This statement is also visible in the response curve for the predictor variable “Land use intensity evolution” of the general MaxEnt model result (figure 17, nr. 2). The sharp increase of the predicted value (nr.1) at the beginning is probably related to a natural disturbance which permitted the encroachment of the species. Also areas without a change in management intensity over time have proved to be particularly significant. Even though, the response curve shows that areas going through a higher management intensity are favourable (nr.3). Areas that in the past were rarely used and today have a greater management intensity, can represent an entrance for the species spread. Probably, the species can take advantage of the construction of new roads and buildings, and the consequently forest opening and better light conditions represent suitable site conditions for its encroachment.

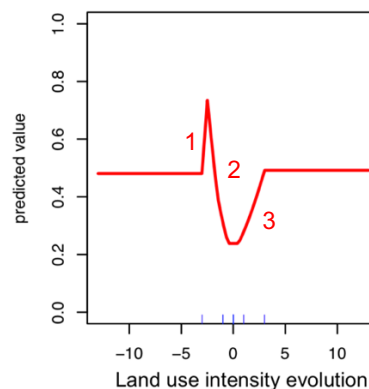


Figure 17: Response curve for the predictor variable of the land use management intensity evolution.

The obtained results show that the land use management intensity and its evolution plays a major role in the encroachment process of post-cultural tree species compositions as well as ecosystem functions (Muster, Elsenbeer, and Conedera 2007; Brovkina et al. 2017; Alexander et al. 2018).

Most of the hypothesis related to anthropogenic disturbances, for most of the analysed variables have been verified. The results show that the land use management intensity enabled to quantify and investigate inter-specific competition dynamics of tree species. However, we must consider that the selection of categories of land use classification and their association to management intensity values is subjective, and therefore can include some errors. In addition, the subdivision of the coppice stands into the different stages based on the SWISSIMAGEs was not always intuitive and sometimes very subjective. Therefore, the subdivision can include some inaccuracies.

#### 4.1.2 Distances from roads, railways, vineyards and rivers

Several variables, can be considered as an anthropogenic disturbance on the forest, since their construction or maintenance causes a canopy opening, better light conditions and also imply a certain degree of management. Regularly, the forest in proximity of the selected variables is cleaned, thus creating theoretically favourable conditions for the encroachment of the species.

In both study site, the black locust populations are overrepresented at a distance of 50-100m from the old/new main roads (figure 18A – B). Supposing that the old and new main roads can have an influence on the presence of the species at such a great distance is very unlikely. On the other hand, we can also argue by considering the land use management intensity. The new main roads experience maintenance interventions a couple of times a years, potentially creating favourable light conditions. However, the higher land use management intensity make this condition unfavourable, and therefore the species remains underrepresented in nearest neighbourhood. In contrast, the distances to the new secondary roads in Stabio are very significant. This could be explained by the fewer maintenance interventions of secondary roads and the resulting lower management intensity, thus favourable conditions.

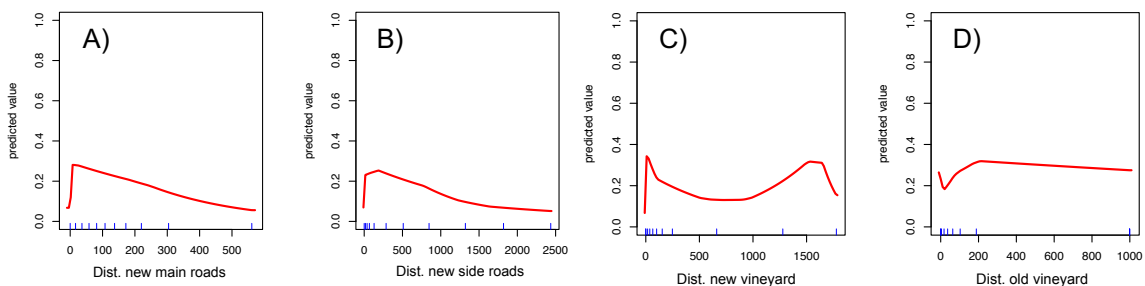


Figure 18: Response curve for the predictor variable of selected variables related to distances

Contrary to what we have expected, the areas in proximity to railways (Vítková *et al.*, 2017), only significantly overrepresent the species in distances greater than 50m. By looking more closely at the land use classification, it can be observed that the species colonization is probably reduced by physical barriers rather than ecological factors (See figure 26 – 27 in the appendix I). The railways of Stabio are too far from the main areas of black locust to have a direct influence on their distribution. Instead, the railways of Chiasso and the nearest encroached area are separated by a main road which potentially implies a higher management intensity.

Concerning the analysis of the distances from the old and new vineyards, only distances greater than 50m resulted significant. This goes far behind our expectation, that areas going through an abandon, such as vineyards, experience a higher colonization (Burkhardt 2017; Vítková *et al.* 2017). Even here the cleaning of vineyard borders would have

been expected to generate favourable conditions. Unfortunately, because no vineyard area in the study sites has been abandoned, neither areas became smaller through the years, the initial hypothesis could not be verified. The response curve of the general MaxEnt model for the respective variables (figure 18C) confirms the one obtained with the MCS. The initial decrease of the predicted value in the first 20m of the predictor variable “Distances from old vineyards” (figure 18D) can be explained by higher management intensities as compared to the present one.

Rivers represent favourable ecosystems for the establishment of invasive neophytes. They facilitate the dispersion of seeds and the continuous fluctuation of water level creates pioneer sites with low competition (Haag 2013; Vítková, Tonika, and Müllerová 2015; Höfle, Dullinger, and Essl 2014). The overrepresentation of black locust at a distance greater than 50m from rivers, can maybe be explained by competitiveness. Perhaps, more competitive species or a combination of different other variables do not allow its growth. This can be also interpreted from the response curve for the river variable of the general MaxEnt model, which in the first 20m shows a sharp decline in the predicted value (figure 19). In Höfle et al. (2014) it is even stated that the persistence of black locust in such areas is mainly controlled by stand age, with the probability of persistence decrease in older stands. Considering the coppice stands around the river, this is not always a plausible explanation. On the other hand, we must consider that many studies have been focusing on alluvial- or floodplain areas (Buzhdygan et al. 2016; Höfle, Dullinger, and Essl 2014) and a comparison with other river or forest ecosystem is difficult. In any case, according to the favourable conditions characterizing this areas, we would have expected a higher significance.

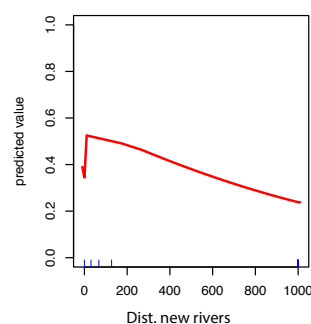


Figure 19: Response curve for the predictor variable “Distances to new rivers”

Finally, the obtained model response curves for the predictor variables in general verify the result of the MCS. To improve the result of these variables, other parameter can be added to the study design. For example, the consideration of the distances from propagule source (seeds, mother trees) and its dispersal mechanism are other factors driving the establishment of invasive neophytes (Dyderski and Jagodziński 2018).



## 4.2 The influence of natural disturbance

As in Burkhardt (2017), post fire areas, significantly overrepresents the species. These results confirm the initial hypothesis, that the encroachment of the species is favoured in areas opened up following a natural disturbance. Fires are relevant processes for maintaining species richness and ecosystem functioning and represent favourable conditions for many invasive neophytes (Wagner and Fraterrigo 2015). Reduced competition, increased nutrient availability, increased temperatures and light availability are beneficial conditions in burned forests. It's not surprising that due to the pioneer character, competitiveness and favourable site conditions the black locust easily encroach these areas. The ability of the species to re-sprout and the vegetative regeneration also facilitate the invasion. Other driving factors are the fire intensity and frequency. Superficial fire not always permits a sufficient opening and cleaning of the forest to enable favourable light conditions for pioneer species. In this case, the original vegetation is still able to recover. Instead, an elevated forest fire intensity may change the forest environment drastically, facilitating the upcoming of new species (Maringer et al. 2012). Even if the post fire areas of Chiasso are small (see figure 12), the MCS and the general MaxEnt response curve (figure 14) were able to give very significant results.

Unfortunately, the areas mapped with rock fall risk have not resulted significant neither in the MCS neither in the general MaxEnt model. We would have expected a higher significance, as it is described in Burkhardt (2017) and Vergani et al. (2017). Since most of the broadleaf forests at lower altitudes are often managed as coppice systems, their high stem density, their rapid growth and the permanence of root systems made this arrangement suitable for slope stability (Vergani et al. 2017). The black locust thick root system and the tolerance to stem injuries caused by rock falls, are beneficial qualities. Protective forests require onerous and continuous maintenance interventions, and can represent favourable circumstances for the encroachment, as the canopy opening allows more light to penetrate in the forest and the steeper slopes more competitive advantage.

The post landslides areas show a similar result as for the past fire areas. Probably, for the same reasons, the species take advantage of these conditions and is more competitive than other. The ability to stabilize slopes with their root enforcement which contributes to increase the soil shear strength and the tolerance to wet-environments confirms his protective function. Nevertheless, more studies in this direction are still needed (Vergani et al. 2017).

### 4.3 The influence of orographic parameters

The species, is significantly overrepresented in altitudes between 300 – 450m a.s.l., in areas with slopes ranging from 30 – 45%, and on slopes exposed to the northwest in both study sites. Instead, it is underrepresented in altitudes lower than 300m a.s.l., on slopes exposed to the southwest and in areas with lower slopes (<15%).

Nevertheless, these MCS results do not implicate that the black locust cannot grow at lower elevations, but considering the elevation bands, they only cover a restricted part of the colline one. The same thought applies for the slope values. For example, the elevation of the study site of Stabio only ranges between 300 – 450m a.s.l.. The analysis of Burkhardt (2017) also covered higher elevations, and resulted to be not significant for the encroachment of the species. This maybe confirms the assumption of Pauchard and Alaback (2004), that microclimatic variations related to elevation may physiologically disfavors the upcoming of invasive neophytes. Low-elevation areas are also thought to be more prone to be invaded by neophytes, due to higher anthropogenic influence and land use (Pauchard and Alaback 2004).

Unfortunately, our areas do not present slopes greater than 45% and therefore no further analysis is possible. On the other hand, in Burkhardt (2017), greater slopes significantly overrepresented the species. These areas mostly correspond with the rock fall areas. Another study, conducted in the Andes showed that areas with greater slope values in proximity to side roads particularly favor the colonization of invasive arboreal and woody neophytes. The competitive advantage and the reduced land use management intensity near side roads probably explains this correlation (Pauchard and Alaback 2004). Therefore, the consideration of different variable combinations can widen the knowledge about invasive neophytes distribution dynamics.

Considering the aspect, the MCS analysis did not confirm the thermophilic character of the black locust, as it was in Burkhard (2017). According to the thermophilic character, warm south facing slopes should favor the species encroachment (Brändli 1998; Vítková et al. 2017). Probably, other factors and site-specific conditions inhibit its growth in these exposures. On the other hand, as it is described in Dydersky and Jagodziński (2018), areas with low light availability can be still favorable for the establishment of invasive arboreal or woody neophytes. This particularly if propagule sources are available (Dyderski and Jagodziński 2018).

Ultimately, the initial hypothesis that foothill zone exposed to the south are the most suitable, was rejected. However, site-specific conditions, and a combination of different other factors enable the growth of black locust in more uncommon areas. A further analysis distributed on more sites including more than only the colline elevation band in the Canton Ticino could certainly improve the understanding of these observations.

## 4.4 Limitations

### 4.4.1 Digitalization of the black locust

The present mapping of the black locust, based on the drone images, proved to be a cost-, and time-effective method. Even though, some inaccuracies are detectable. Depending on the spatial resolution of the drone images, in some areas the mapping remains subjective. A challenge was to accurately identify young individual trees and those one sheltered by others. For these reasons, the field control was absolutely indispensable to improve the accuracy of the mapping. Overall, in Chiasso, 88.1% was mapped correctly directly from the drone image, 2.7% missed in the mapping, and 9.1% added based on the field control. Instead, in Stabio, approximately 72.9% was mapped correctly, 2.7% mapped wrongly and removed, and 29.8% added. Most of the error happened when young black locust trees were not directly visible on the images, or the trees were sheltered by other. However, the difficult terrain did not always allowed to check all the areas of the study sites, especially those with a marked slope and an elevate forest density, have made the field control laborious.

The assumption of minimal black locust distribution between 1940 – 1950 made its mapping negligible. The possession of quantitative historical forest data can represent a new way to improve the reliability of this assumption. Dendrochronological analyses of old black locust trees in the study sites could also represent a validation method. Luckily, Bonacina (2014) made a few dendrochronological analyses in the Mendrisiotto region. Distributed on 5 transects, one of them in Chiasso and another in Stabio, the analysis showed that out of 60 tree samples only two were between 60 – 70 years old (Bonacina 2014). This indicates that the initial assumption for the selected study sites can be verified.

Finally, this rapidly emerging tool for local-scale monitoring represents a useful and time-effective method to monitor the distribution of invasive neophytes and environmental phenomena more in general (J. Zhang et al. 2016; Lin et al. 2015; Getzin, Wiegand, and Schöning 2012). Unfortunately, one drawback is the relative expensive data acquisition and the post-processing of the images is not always intuitive. For this reason, a lot of training is needed (Lin et al. 2015).

### 4.4.2 Uncertainty in the Monte Carlo Simulation

The MCS is a statistical method performed with points. For this thesis, the points should represent areas with different characteristics. The encountered problem was to find a suitable method to represent the observed/real distribution of points (*true value*), namely those points distributed solely on the areas encroached by black locust. In spite of using the centroid of each polygon, we generated a number of random points within this areas. Consequently, each polygon, regardless of its area is more or less equally represented in the

analysis and there isn't an underrepresentation of larger polygons. This distribution also equals more to a real one and is therefore feasible. Nonetheless, the number of random points was chosen arbitrary. According to Denning and Wood (2012), the higher the number of points, the more accurate and robust the results of the MCS. Considering the number of points generated in each study sites, we can assume a high accuracy and the number of repeated runs (9999) ensures a high strength of statistic outputs. However, depending on the environmental issue to be analysed, data can be lacking and missing. On the other hand, a huge amount of data can also result in long computing-time (Denning and Wood 2012).

Another encountered drawback was to approximate the proportion of the areas of the respective variables and categories, calculated by considering the number of points in each category. For the variables those areas could be calculated with ArcGIS, the results were confronted with the proportion of areas calculated with the points (Appendix III – Table 20 – 21). In general, the results show a good accordance. Even though, this point system creates an inaccuracy in the calculation of the proportion of areas and of distances. The distances from the points representing the species to vineyards, roads, railways and rivers do not represent the real shortest distances but the distances from the different random points within the area encroached by the species. Through this, the results are fractionally distorted and tendentially the error is magnified in larger polygons or in polygon containing a lower amount of points.

For minimizing these errors other possibilities exist, but for the past noted effectiveness of the methodology (e.g. Carmel et al. 2009, Burkhardt 2017, Conedera et al. 2011), the MCS was selected to be suitable. Changing the analysis approach by considering areas rather than points would probably have been able to increase the accuracy of the results. However, such analysis design would have been extremely difficult and time-consuming. The chosen design was therefore, despite some limitations, a feasible and achievable approach, which, nevertheless was able to provide satisfactory and robust results.

#### 4.4.3 Uncertainty in the model generation

MaxEnt is an intensive, and depending on the amount of data even time-consuming modelling approach. For larger areas, longer computing time should be taken into consideration. Another drawback is the missing of a temporal dimension in our study design. Since the model considers presence-only species records, temporal variables are not included. This can be improved by considering variables as the temperature and precipitation under different climate scenarios.

To validate the model, the cross-validation would have surely have improved the accuracy of the results. However, considering the areas encroached by black locust as validation data, can also represent a confident method. As it is visible in figure 20, the

generated notched boxplots show how the general MaxEnt model is able to discriminate between presence and absence of the species in each study site and in overall areas. The results of the non-parametric Wilcoxon Test (rank sum), represented with little stars above the boxplot, indicate that the presence and absence medians significantly differ. The p-value for all independent sites is  $2.2 \cdot 10^{-16}$ . Nevertheless, the model seems to discriminate best in the study site of Sementina and Stabio whereas in Chiasso the difference between the medians is smaller. However, none of the 95% confidence intervals overlaps within the individual study sites, indicating a good discrimination capacity of the model.

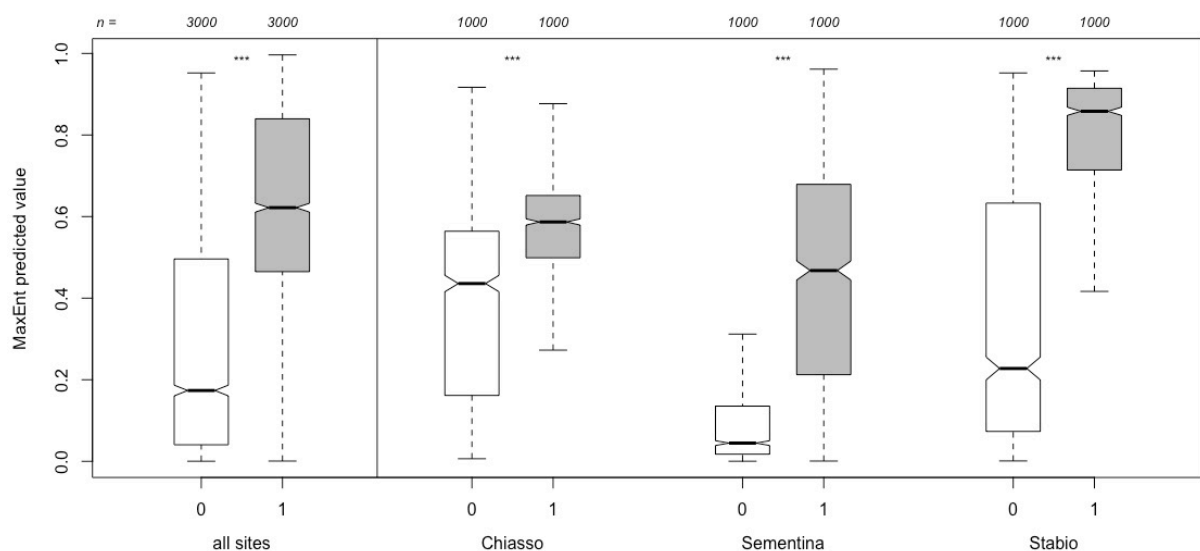


Figure 20: The boxplots for each site represent the ability of the general MaxEnt model to discriminate between the presence (1) and absence (0) of the black locust. The sample number utilized is indicated above the boxplots and the significance of the Wilcoxon Test with stars.

The MaxEnt modelling misses assigning a statistical weight to the single variables. This can imply that land managers, authorities or other stakeholder need to collect an important amount of data to run the model. Sixteen variables were held in the realization of the general model. These variables, however, do not exhibit any statistical weight as in the linear mixed model approach, and therefore it is not possible to quantify the importance of each predictor variables. The huge amount of held variables into the model calculation could be improved by checking whether the variables present autocorrelation or not. Since the field of multivariate statistics offers different possibilities to investigate the relationship between variables, adopt a Multiple Linear Regression can be a solution to solve the missing of statistical weights of the single predictor variables.

According to many studies, the use of only the AUC to evaluate the model performance can be misleading. It provides no information on the spatial distribution of wrong predicted presences and absences and weights omission and commission errors equally. For this reason, the reliability of the model should be evaluated with separate analyses for

commission and omission errors (Lobo, Jiménez-valverde, and Real 2008; K. Zhang et al. 2018).

A comparison among other invasive arboreal or woody neophytes treated with the same approach could also give new insights into invasive neophytes processes and can provide a starting point for new management options more in general. Since previous studies (West et al. 2016; Merow, Smith, and Silander 2013; Sharma et al. 2018; Dicko et al. 2014) show that MaxEnt can be used for different kind of environmental issues, and is able to provide satisfactory results it provides a valuable method to predict the habitat distribution of invasive arboreal neophytes. Other model approaches could be the use of a Principal Component Analysis (PCA) which is able to reduce a large set of variables to a smaller one that still contains most of the information (Abdi and Williams 2010).

To generate the probability distribution of the model results, we used an IDW interpolation. The choice of the radius, the number of neighbours and distance weighting are arbitrary chose parameters which influence the interpolation result. However, the interpolated surface varies smoothly and equals to a real growth of the black locust, e.g. it's very unlikely to have sharp boundaries in its distribution as an invasion usually happens gradually. In addition, considering the huge amount of data used for the model generation, we can assume a good interpolation accuracy. Even by using other deterministic interpolators, the results only showed slightly different surfaces.

Even if the model present some drawbacks, for land managers, authorities, and other stakeholder it can represent an effective method to analyse the spread strategies of arboreal or woody invasive neophytes and can be adopted as a decision support-system, even with only sporadic datasets. Although modelling always entails uncertainties, land managers should not bear their decisions solely on this uncertainties, but rather use them to handle their management efforts.

#### **4.5 Management suggestions**

The black locust, present for more than 60 years in the southern Alps, has nowadays become naturalized and become part of the cultural landscape in many European countries. Actually, no effective control measures of the species exists (Vítková et al. 2017). The incredible resprouting ability even after cutting or burning affected areas doesn't permit an efficient eradication. Repeated cutting can maybe cease the tree but needs a laborious removing of the resprouting material. Instead, chemical agents are not always successful, neither permitted in forest, nature conservation areas and areas in proximity to water in Switzerland (ORRChem 2005). Therefore, mechanical approaches are recommended.

From the ongoing knowledge, guidelines (Monaco and Genovesi 2014; Wittenberg et al. 2005; BAFU 2016) and based on the results of this study, we can suggest the following management practices (figure 21).

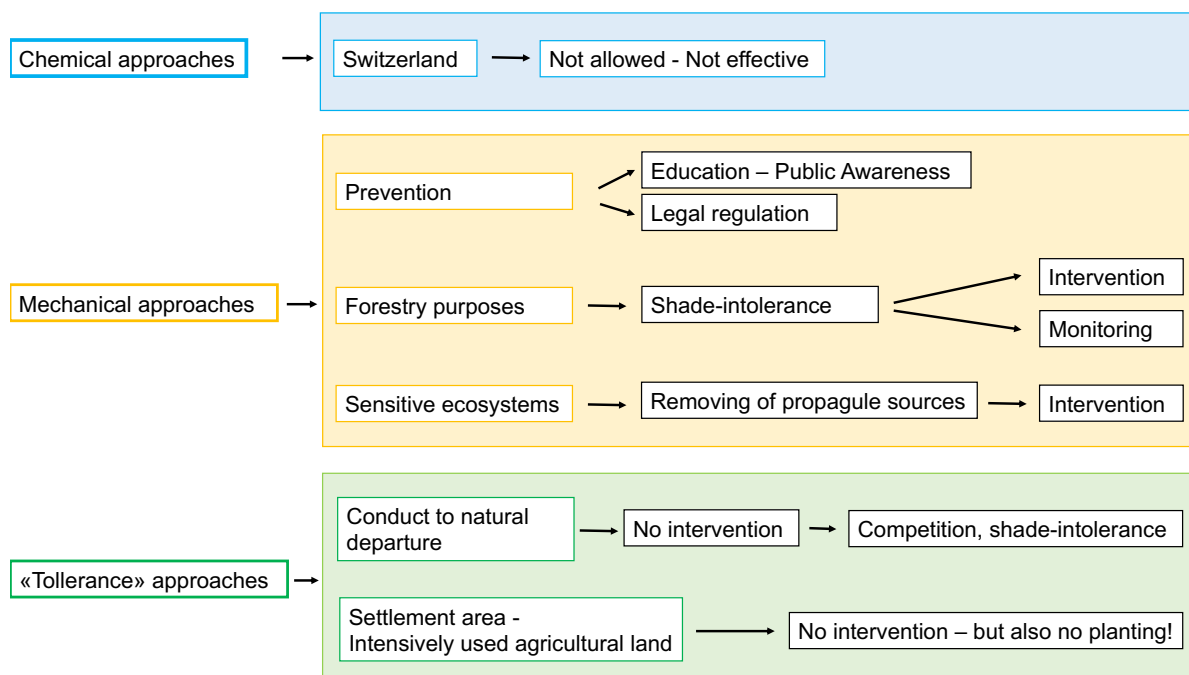


Figure 21: Suggested management options subdivided into three categories: chemical-, mechanical-, and “tolerance” approaches. Since most of the chemical options are not allowed, we recommend to focus on the other two.

The first management suggestion is to encourage a responsible behaviour by private individuals and industries against invasive neophytes, disadvising to plant species listed as invasive as ornamental plants in private gardens. Even if the awareness among scientist and authorities is high, the problem is not always perceived in suburban and urban areas or private landowner. Future education and communication efforts should be broadened to include as more residents as possible (Ma, Clarke, and Church 2018). The prevention phase (see figure 1) including a far-reaching education regarding the issue and legal regulation remains the most cost effective management option.

If, on the other hand, the species encroachment is already at an advanced stage and the eradication is no longer a feasible option, another possibility is to conduct the black locust to its natural departure, namely avoid to intervene in the affected areas. If the black locust is left in its natural environment, it is likely that more competitive and shade-tolerant species tend to drive it away. This suggestion open a new cost effective management option for forest without a natural conservation role, without direct intervention on the forest.

Instead, if the black locust wants to be used for its economic value (forestry purposes), it will probably be necessary to consider different maintenance interventions, in order to provide the best condition for its aging. This particularly due to its shade-intolerance. Defining specific forestry goals and operating plans are surely a good starting point to rationalize

working funds and maintenance costs. Nevertheless, on poor sites, also the enrichment of nitrogen stores into the soil can be beneficial for the upcoming of future plants.

On the other hand, propagule pressure and its dispersal also influence the encroachment success of the species (Conedera et al. 2017). The establishment of invasive neophytes is facilitated if propagule sources are abundant and its dispersal is effective. This mainly depends on the presence and distance to mother trees and the resprouting capacity of the species (Dyderski and Jagodziński 2018). Dyderski and Jagodziński (2018) showed that especially areas with lower availability of seeds or sprouts are less invasible than those with higher propagule sources. Thus, removing propagule sources in sensitive environments can be a precious management suggestion. Even though, if the species is actively planted for his economic value, stand monitoring is recommended to reduce the undesirable impact on sensitive ecosystem in proximity of the productive stands (Dyderski and Jagodziński 2018; Vítková et al. 2017).

Based on the results of this study, special attention should be given to areas experiencing a lower or higher management intensity. These situations can represent a facilitated access for the encroachment of the species. Due to its pioneering character areas previously affected by natural disturbances and areas with slopes greater than 30% are easily colonized. In addition, depending on the management intensity in proximity to side roads and vineyards, management options should be defined according to this drivers. Also the severity of a disturbance, either natural or anthropogenic, and depending if it happened in the past or in the present plays an important role in the spread success of the species. In fact, past disturbance, as for example a fire event or a coppice stand which became unmanaged through the years, can have completely another effect compared to present disturbance as for example the construction of a new road.

The suggestion is therefore to adopt a site-specific management approach that not only consider the evolution of the land use management intensity and silvicultural strategies but also the proximity to features showing a driving force on the expansion of the species. The needs and goals of landowner, authorities and residents as well as cultural and ecological circumstance should enable an efficient and integrated management of the issue. Finally, according to Pergl et al. (2016) and Vítková et al. (2017), the following general management strategies on black locust are recommended:

- I. Control or gradual suppression in undesirable forest stands
- II. Their control in sensitive ecosystems such as in dry grassland, or forests
- III. The tolerance on intensively used agricultural land and settlement areas



## 5. Outlook and conclusion

The methodologies used in this master thesis has permitted to generalise the invasion patterns of the black locust and to discover the potential drivers on its encroachment dynamics. Although the pioneering character of the species tends to rapidly colonize different type of ecosystems, the analysis showed that after more than sixty years of presence in the Canton Ticino, its distribution is particularly driven by the management intensity, its evolution, medium and mature coppice stands, greater slopes, fires and distances to vineyards and roads. The hypotheses are proved for these specific drivers but rejected for specific anthropogenic influences and for its thermophilic character. The often simultaneously or more complex interaction with other factors, has not allowed to directly deduce casual relationships from the observed correlations. In this relation, the results warrant further investigation. Additionally, depending if a specific disturbance happens in the past or in the present can have completely other influences on the encroachment dynamics of the species.

Although robust and reliable methodologies were adopted, the study design can still be adapted. Consider climate variables or soil parameters are further potential factors to include in the analysis. The availability of propagule sources, its distance to mother trees and its dispersal mechanism also can improve the understanding of general invasion patterns of neophytes. Create a model that predict the evolution of the species in the following years, incorporating climate variables, can be a further step to handle correct invasive species management solutions. Adopting this methodology over a wider area of Switzerland, considering more than three small sites, can be a starting point for further research and give additional information about an issue getting more awareness among communities and authorities. Because the success of invasive neophytes depends on the species' introduction history, present uses, ecological- and climatic requirements, we recommend a site-specific evaluation to find the best management solution.

Because the species became naturalized, it can represent a model to understand the encroachment dynamics of other invasive arboreal neophytes on a longer run. The methodology, even considering the few drawbacks, can be used to observe the behaviour and distribution of other invasive neophytes (e.g. *Ailanthus altissima*) and emphasizes the usefulness to analyse relevant environmental issues. On the other hand, the MaxEnt model is widely used to predict species distribution and proved to be helpful to generalize the distribution of the black locust. The study design can be used as a decision support system for future forest management applications, not only for Switzerland. Since the legal regulation among Central Europe countries differs, it will be of major importance to find common solutions and to develop action plans for an integrated management, based on site-specific approaches ranging from tolerance of the species at selected areas and eradication at valuable sites (Pergl et al. 2016).

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# Appendix

## Appendix I - Figure

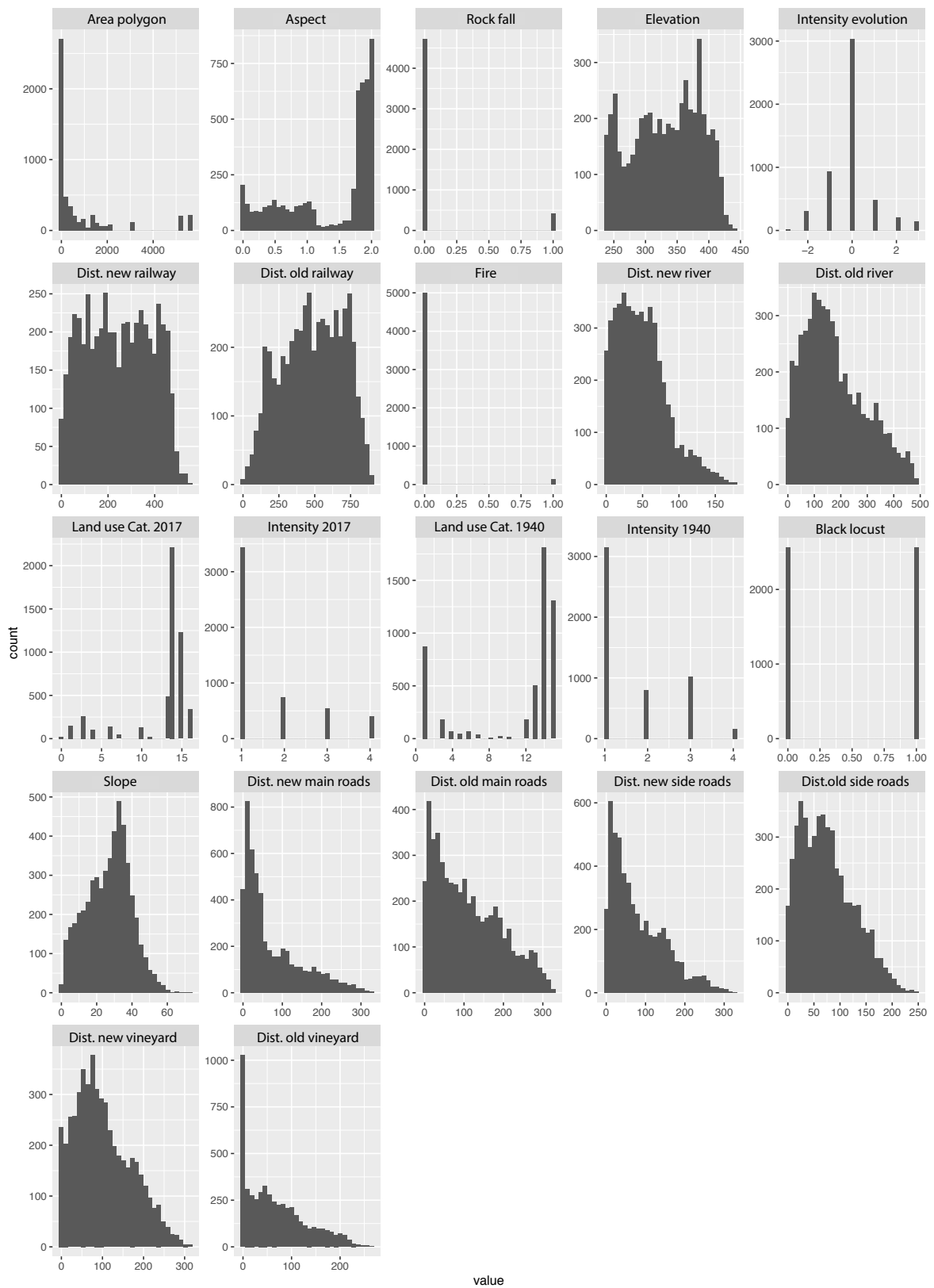


Figure 22: Distribution of the different variables in the study site in Chiasso. The histograms were used to define the different categories then used for the MCS

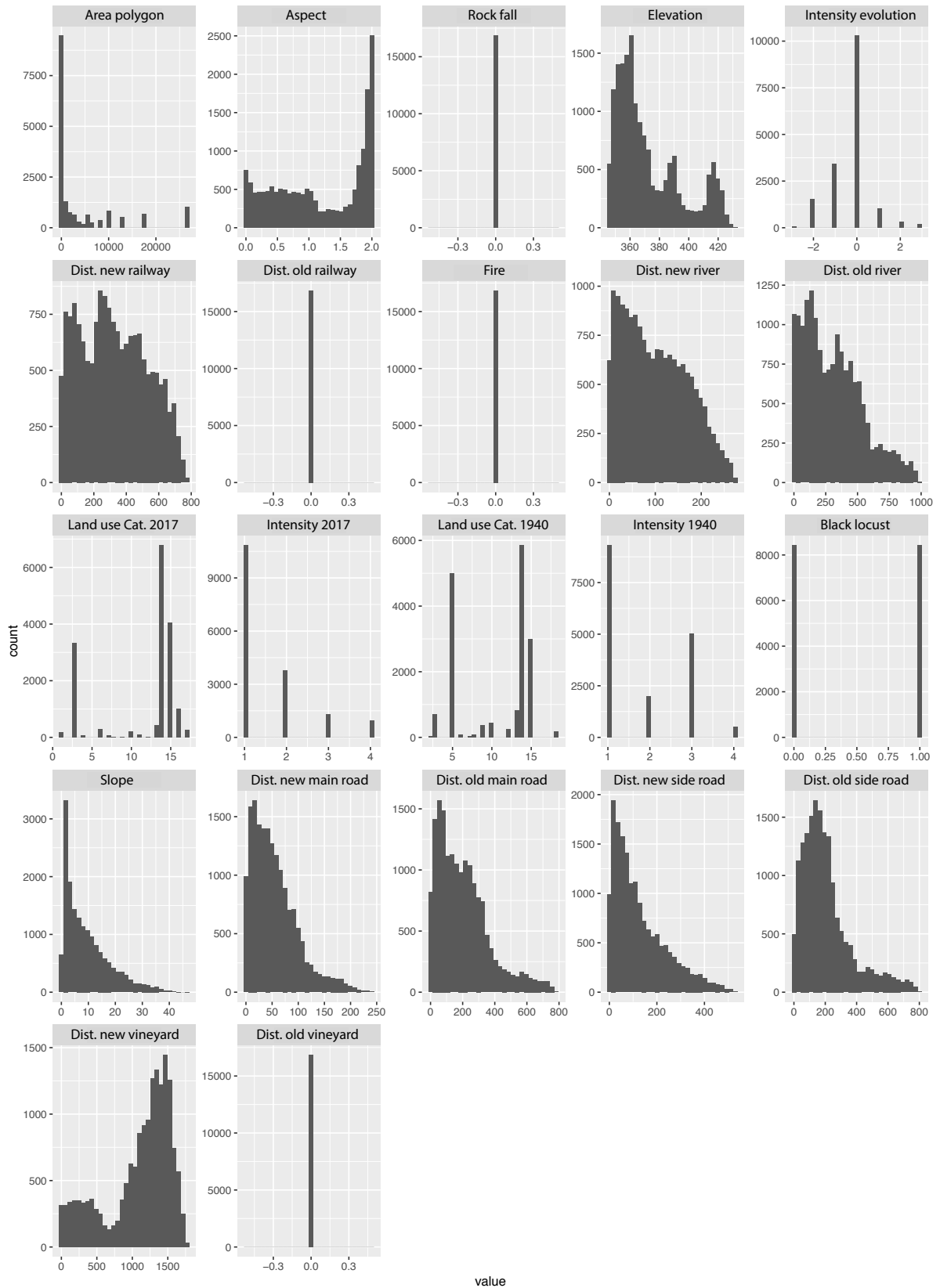


Figure 23: Distribution of the different variables in the study site in Stabio. The histograms were used to define the different categories then used for the MCS

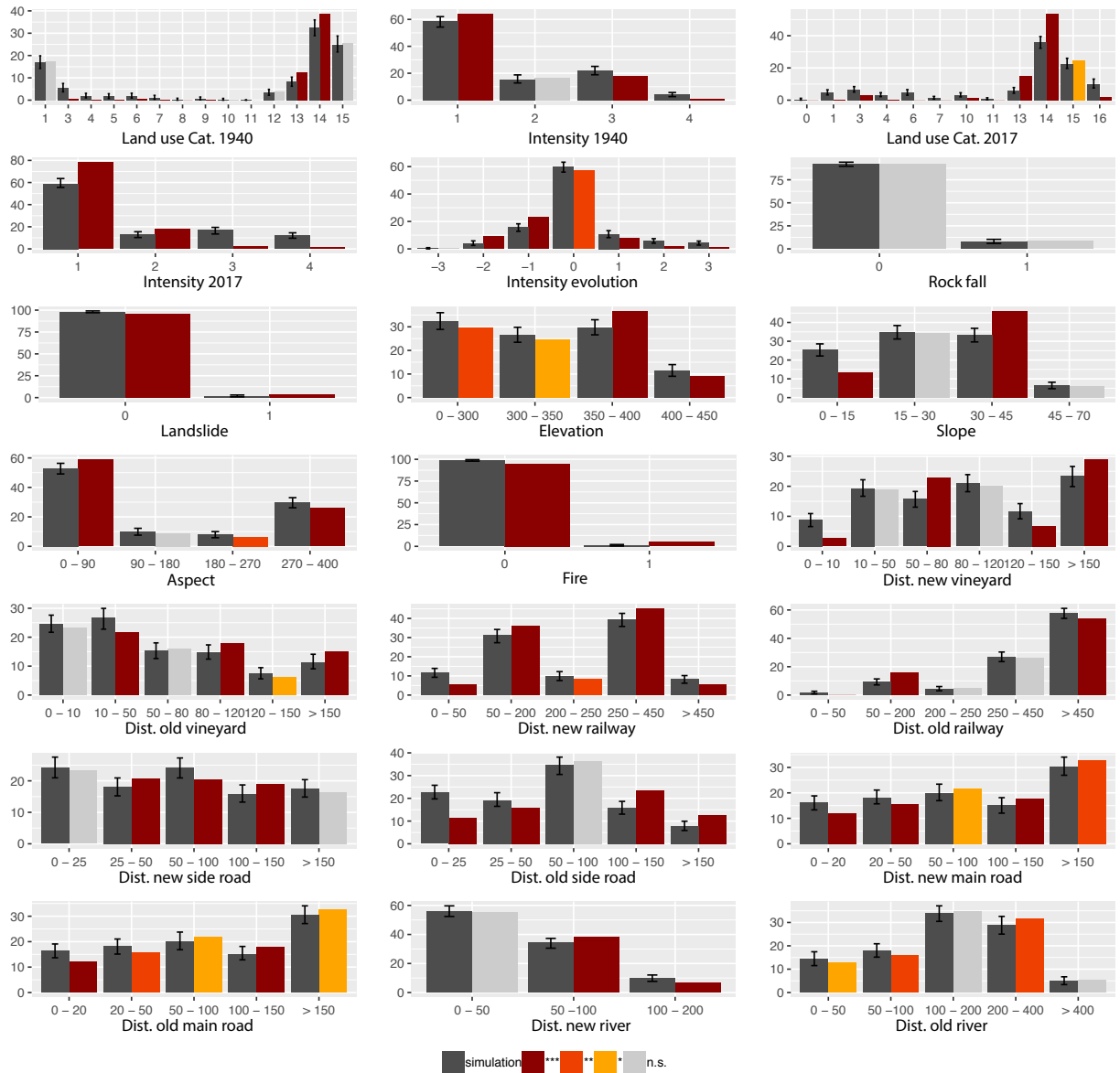


Figure 24: MCS-Results represented with histograms and geometric error bars for the study site of Chiasso



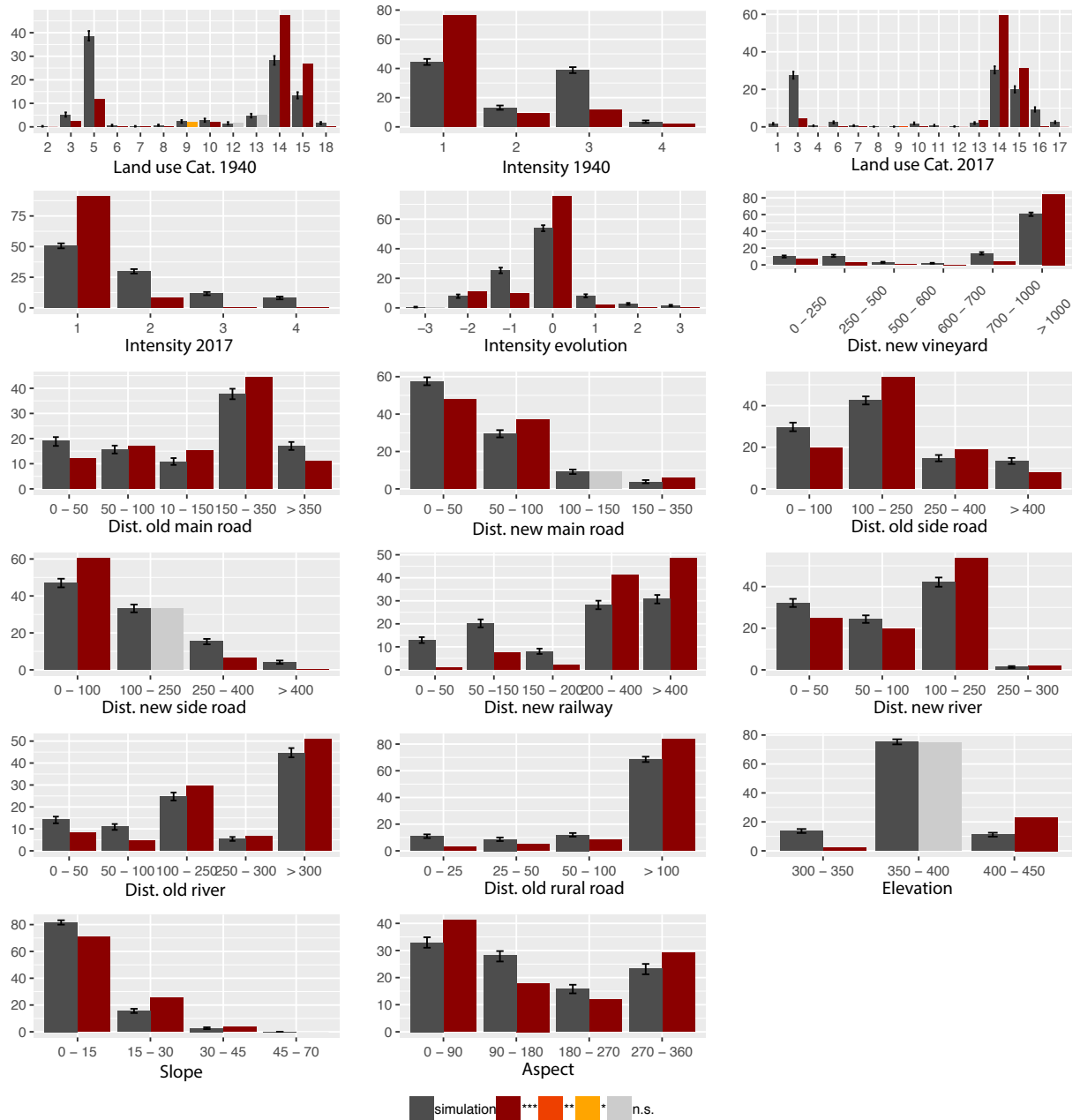


Figure 25: MCS-Results represented with histograms and geometric error bars for the study site of Stabio

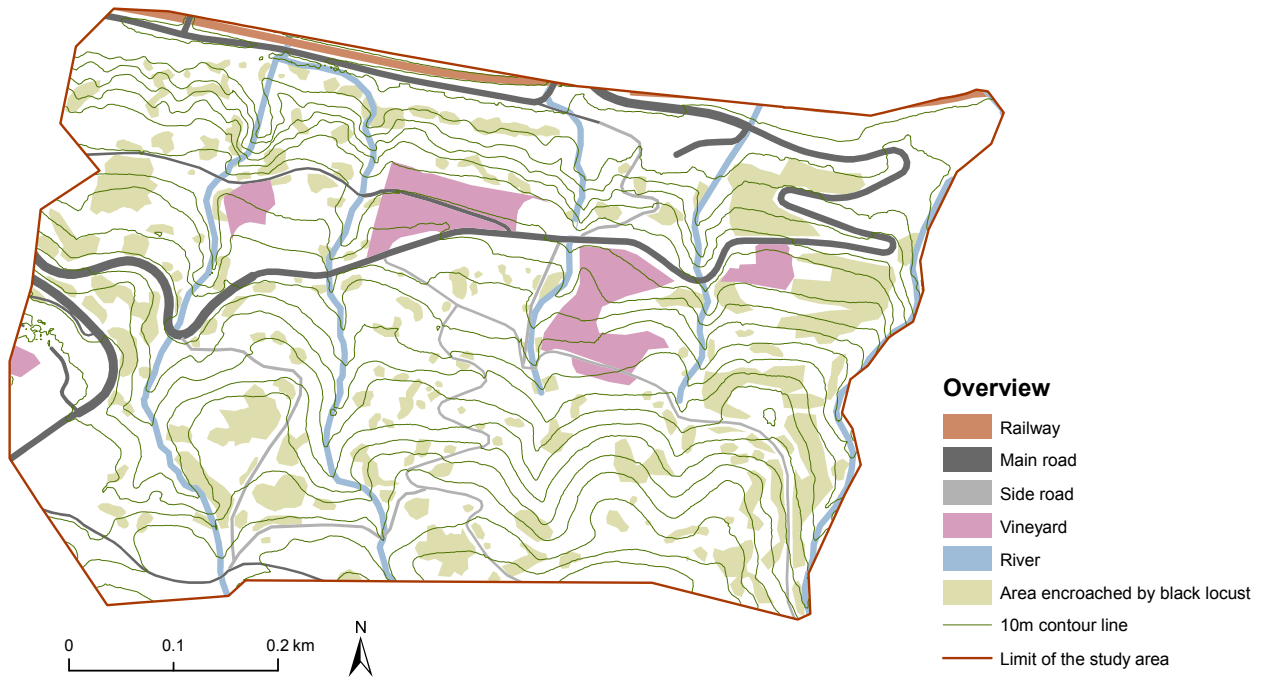


Figure 26: Representation of the study site of Chiasso with selected variables related to distances to different features and the areas encroached by the species

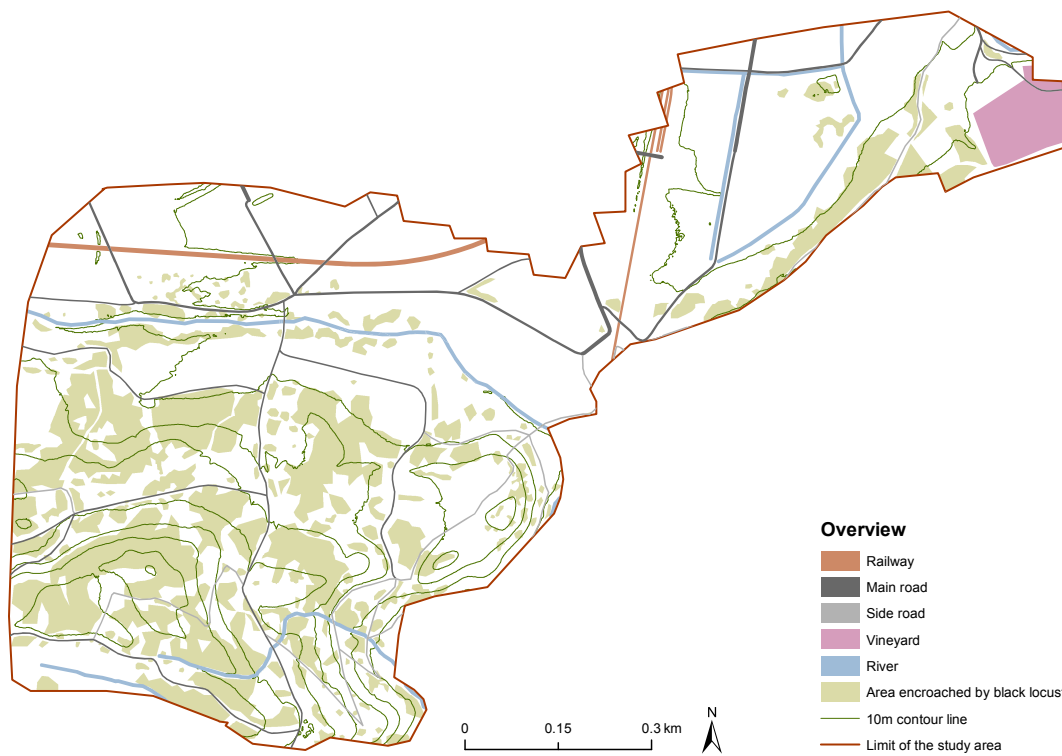


Figure 27: Representation of the study site of Stabio with selected variables related to distances to different features and the areas encroached by the species

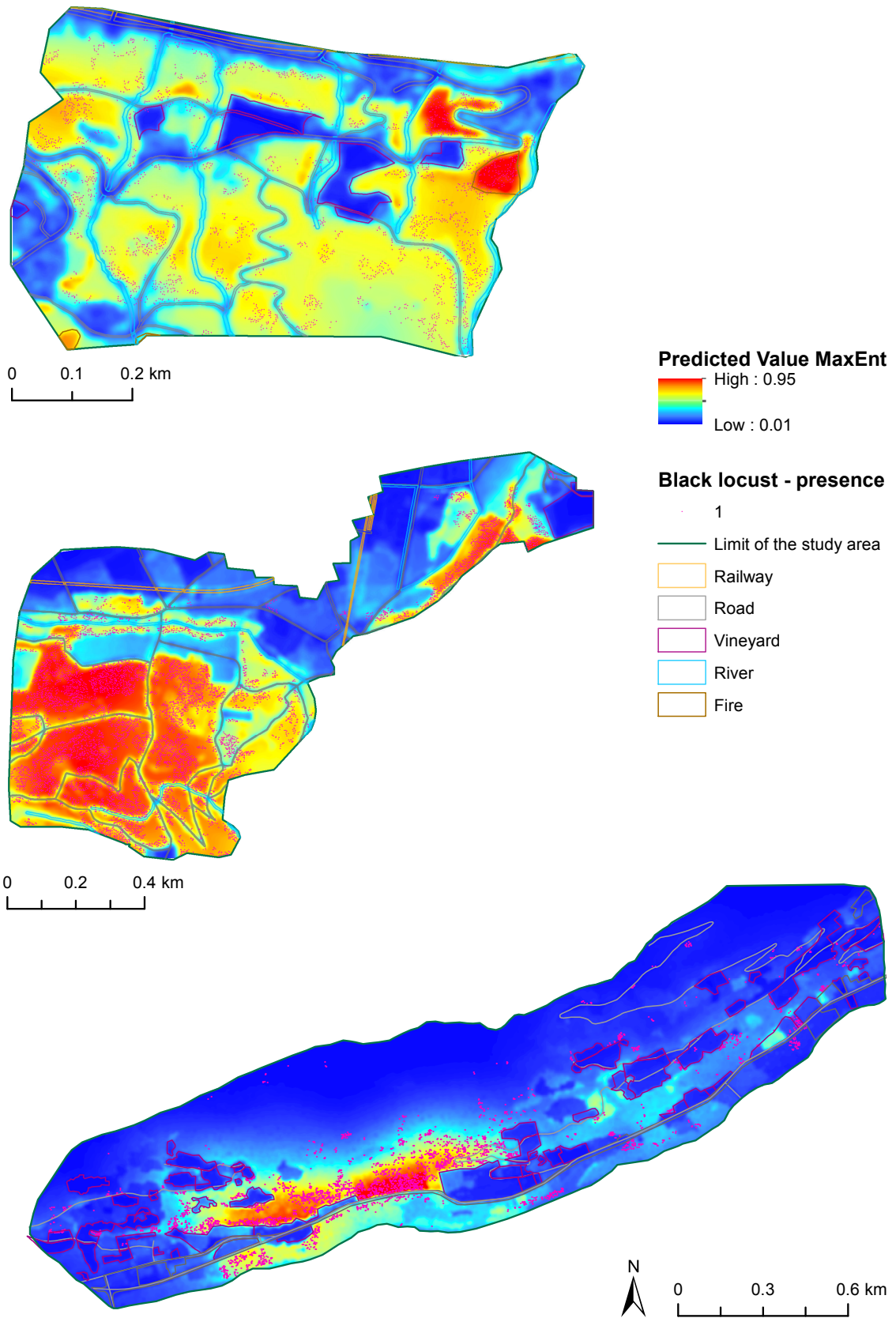


Figure 28: Result of the probability maps calculated with the MaxEnt model. For a simpler interpretation of the encroachment dynamics of the species, selected variables were added to the probability maps.

## Appendix II - Table

Table 18: Frequency of black locust in relation to the variable old rural roads, old and main roads of the two study sites

		Value	0 - 50	50 - 100	100 - 150	150 - 350	> 350
		<b>Stabio</b>	<b>Old main roads</b>	True value	12.24	17.19	15.10
Max	20.59			17.20	12.24	39.80	18.64
Min	17.07			14.07	9.52	35.64	15.47
Mean	19.04			15.63	10.83	37.63	16.88
Significance	---			+++	+++	+++	---
<b>Value</b>	<b>0 - 50</b>			<b>50 - 100</b>	<b>100 - 150</b>	<b>150 - 350</b>	<b>&gt; 350</b>
<b>New main roads</b>	True value		47.74	36.89	9.36	6.01	-
	Max		59.68	31.42	10.33	4.70	-
	Min		55.45	27.55	7.94	3.00	-
	Mean		57.48	29.68	9.08	3.76	-
	Significance		---	+++	n.s.	+++	-
	<b>Value</b>		<b>0 - 25</b>	<b>25 - 50</b>	<b>50 - 100</b>	<b>&gt; 100</b>	
<b>Old rural roads</b>	True value		2.94	5.28	8.17	83.60	
	Max		12.32	10.01	13.36	70.54	
	Min		9.56	7.31	10.63	66.58	
	Mean	10.92	8.63	11.92	68.53		
	Significance	---	---	---	+++		
	<b>Value</b>	<b>0 - 20</b>	<b>20 - 50</b>	<b>50 - 100</b>	<b>100 - 150</b>	<b>&gt; 150</b>	
<b>Chiasso</b>	<b>Old main roads</b>	True value	12.08	15.74	21.70	17.76	32.72
		Max	19.32	21.39	22.83	17.69	33.62
		Min	13.63	15.50	17.30	12.54	26.84
		Mean	16.28	18.25	20.02	15.11	30.34
		Significance	---	--	++	+++	++
		<b>Value</b>	<b>0 - 20</b>	<b>20 - 50</b>	<b>50 - 100</b>	<b>100 - 150</b>	<b>&gt; 150</b>
	<b>New main roads</b>	True value	24.11	26.41	16.05	13.56	19.87
		Max	34.67	30.15	18.82	12.43	19.01
		Min	27.78	23.72	13.32	8.14	13.21
		Mean	31.26	26.66	15.94	10.16	15.97
		Significance	---	n.s.	n.s.	+++	+++

True value: normalized value of the actual frequency of black locust

Max./Min.: Minimum/maximum normalized value resulting from the MCS

Significance: p-value resulting from the double-tailed statistical test. +++/-- = p < 0.0001; ++/-- = p < 0.01; +/- = p < 0.05; n.s. = not significant

Table 19: Summary table of the qualitative results of the similarity and difference between the different study sites. Note that an empty space means that the comparison was not able to be done, mostly due to the missing of the respective variables in one of the study site.

Site comparison	Anthropogenic disturbances							Orographic parameters			Natural disturbances	
	Land use	Intensity	Evolution	Distances from roads	Distances from railways	Distances from vineyards	Distances from rivers	Altitude	Slope	Aspect	Fire	Rock fall
<b>Chiasso – Stabio</b>	+/-	++	++	+	-	-	+	+	+	+		
<b>Chiasso – Sementina</b>	+/-	++	+	-		-		-	+	+	++	-
<b>Stabio - Sementina</b>	+/-	++	+	-		--		--	+	+/-		

+ +: high similarity; +: similarity; -: difference; --: huge difference

## Appendix III - Comparison of proportions of areas

Table 20: Study site of Chiasso

Variable	Category	Number of points	% Area (Point)	% Area (ArcGIS)	
<b>Altitude [m a.s.l.]</b>	0 - 300	5089	32.21	32.16	
	300 - 350	4214	26.67	26.81	
	350 - 400	4699	29.74	29.74	
	400 - 450	1799	11.39	11.24	
<b>Aspect [°]</b>	0 - 90	8338	52.77	55.08	
	90 - 180	1538	9.73	6.39	
	180 - 270	1259	7.97	4.75	
	270 - 360	4666	29.53	33.78	
<b>Slope [%]</b>	0 - 15	4008	25.37	25.87	
	15 - 30	5508	34.86	33.89	
	30 - 45	5262	33.31	32.28	
	> 45	1021	6.46	6.65	
<b>Fire</b>	0	15612	98.80	97.21	
	1	189	1.20	2.79	
<b>Rock fall</b>	0	14561	92.15	92.25	
	1	1240	7.85	7.75	
<b>Landslide</b>	0	15504	98.12	98.19	
	1	297	1.88	1.81	
<b>Land use 2017 - Category</b>	0	87	0.55	0.58	
	1	753	4.77	4.65	
	3	1051	6.65	6.80	
	4	534	3.38	3.29	
	6	720	4.56	4.56	
	7	228	1.44	1.34	
	10	500	3.16	3.21	
	11	130	0.82	0.89	
	13	940	5.95	5.91	
	14	5701	36.08	35.54	
	15	3585	22.69	22.71	
	16	1572	9.95	10.50	
	<b>Land use intensity - 2017</b>	1	9286	58.77	58.26
		2	1991	12.60	12.71
		3	2640	16.71	17.07
		4	1884	11.92	11.96
<b>Land use 1940 - Category</b>	1	2695	17.06	16.83	
	3	877	5.55	5.80	
	4	297	1.88	1.82	
	5	276	1.75	1.86	
	6	321	2.03	1.94	
	7	185	1.17	1.26	
	8	59	0.37	0.32	
	9	111	0.70	0.79	
	10	40	0.25	0.24	
	11	1	0.01	0.04	
	12	546	3.46	4.86	
	13	1312	8.30	8.24	
	14	5161	32.66	31.81	
	15	3920	24.81	24.18	
	<b>Land use intensity - 1940</b>	1	9251	58.55	57.10
2		2451	15.51	18.90	
3		3440	21.77	19.95	
4		659	4.17	4.05	

Table 21: Study site of Stabio

Variable	Category	Number of points	% Area (Point)	% Area (ArcGIS)	
<b>Altitude [m a.s.l.]</b>	300 - 350	4741	13.70	13.66	
	350 - 400	26050	75.28	75.31	
	400 - 450	3813	11.02	11.01	
<b>Slope [%]</b>	0 - 15	28300	81.78	80.80	
	15 - 30	5387	15.57	15.34	
	30 - 45	914	2.64	2.69	
	> 45	3	0.01	0.02	
<b>Aspect [°]</b>	0 - 90	11395	32.93	35.92	
	90 - 180	9710	28.06	24.09	
	180 - 270	5474	15.82	12.97	
	270 - 360	8025	23.19	27.02	
<b>Land use 2017 - Category</b>	1	564	1.63	1.64	
	3	9511	27.49	27.58	
	4	193	0.56	0.60	
	6	824	2.38	2.19	
	7	223	0.64	0.75	
	8	30	0.09	0.07	
	9	36	0.10	0.13	
	10	648	1.87	1.81	
	11	272	0.79	0.85	
	12	75	0.22	0.20	
	13	700	2.02	2.12	
	14	10560	30.52	2.12	
	15	6896	19.93	19.64	
	16	3242	9.37	9.50	
	17	830	2.40	9.50	
	<b>Land use intensity - 2017</b>	1	17522	50.64	50.29
		2	10286	29.72	29.90
3		4029	11.64	11.89	
4		2767	8.00	7.92	
<b>Land use 1940 - Category</b>	10	989	2.86	2.93	
	12	512	1.48	1.44	
	13	1636	4.73	4.65	
	14	9765	28.22	27.85	
	15	4610	13.32	13.51	
	18	551	1.59	1.64	
	2	81	0.23	0.26	
	3	1807	5.22	5.43	
	5	13329	38.52	38.89	
	6	216	0.62	0.64	
	7	76	0.22	0.24	
	8	247	0.71	0.20	
	9	785	2.27	2.31	
	<b>Land use intensity - 1940</b>	1	15407	44.52	43.87
		2	4587	13.26	13.43
		3	13405	38.74	39.13
		4	1205	3.48	3.57

## Appendix IV – Selected part of the R Skript

```
#####
#CHIASO
#####
# Import of a point-shapefile containing: the random points over the entire study
area in relation to:
# - random points cut on the areas enchroached by black locust
# - Land use 1940/2017 / Categories / Intensity
# - Variables with distances: vineyards, river, roads, railways
# - DEM: aspect, elevation, slope
# - Natural hazards: rock fall, landslide, fire

library(tidyverse)
library(foreign)
library(dplyr)

d <-
read.dbf("/Users/Olly/Desktop/R/Rskript_Chiasso/gis/RandomPoints_C_Rob_Near_LUC_DE
M_PerNat_Fire_final3Copy.dbf", T)

names(d) <- tolower(names(d))

# Calculation of the evolution of land use management intensity

d$evol <- d$luc18_int - d$luc40_int

# i add the variable "evol = evolution" on the already shapefile by mutate. Then,
considering the varibale of natural hazards, i assign the value 0 to all points
which doesn't present the event, and 1 to the points showing the event

d <- d %>% mutate(evol = luc18_int - d$luc40_int,
                 area_fire = ifelse(area_fire>0,1,0),
                 caduta_sassi = ifelse(area_cs>0,1,0),
                 landslide = ifelse(area_ls>0,1,0))

# Based on the histogram distribution of the points in the respective variables, i
cut it into the decided categories

d <- d %>% mutate(spc_o_cat = cut(spc_o_d, c(0,20,50,100,150,2500), include.lowest
= T),
                 spc_n_cat = cut(spc_n_d, c(0,20,50,100,150,2500), include.lowest
= T),
                 ssc_o_cat = cut(ssc_o_d, c(0,25,50,100,150,2500), include.lowest
= T),
                 ssc_n_cat = cut(ssc_n_d, c(0,25,50,100,150,2500), include.lowest
= T),
                 vignc_o_cat = cut(vignc_o_d, c(0,10,50,80,120,150,2500),
include.lowest = T),

                 vignc_n_cat = cut(vignc_n_d, c(0,10,50,80,120,150,2500),
include.lowest = T),
                 fic_n_cat = cut(fic_n_d, c(0,50,100,200,400,2500),
include.lowest = T),
                 fic_o_cat = cut(fic_o_d, c(0,50,100,200,400,2500),
include.lowest = T),
                 fc_n_cat = cut(fc_n_d, c(0,50,200,250,450,2500), include.lowest
= T),
                 fc_o_cat = cut(fc_o_d, c(0,50,200,250,450,2500), include.lowest
= T),
                 elevation_cat = cut(elev_c, c(0,300,350,400,450,700),
include.lowest = T),
                 slope_cat = cut(slope_c, c(0,15,30,45,70), include.lowest = T),
                 aspect_cat = cut(aspect_c, c(0,90,180,270,400), include.lowest =
T))

#####
# Function used for the Monte Carlo Simulation (MCS)
#####

library(tidyverse)
library(lubridate)

# Before starting with the simulation we need to calculate the proportion of land
use (cat, area) and generate an output file with the interested features needed
for the further analysis

# d is a dataframe with column area and cat
# p is a dataframe with the proportions of land use (cat, area)
randomizeFires <- function(d,p, nrand=999, csvFilename = 'results_rand_dplyr.csv'){
  rownames(p) <- p$cat
  p$pc.cat <- p$area/sum(p$area)
  p$cum.cat <- cumsum(p$pc.cat)
  p$true.nr <- apply(p, 1, function(x) length(d[d$cat==x[1] , 1]))
  p$pc.nr <- p$true.nr/sum(p$true.nr)
  p$cum.nr <- cumsum(p$pc.nr)
  p$true.area.mean <-apply(p, 1, function(x) mean(d$area[d$cat==x[1]]))
  p$true.area.median <-apply(p, 1, function(x) median(d$area[d$cat==x[1]]))

  # temp <- (p %>% select(cat, area) %>% spread(cat, area))[-1,] #empty data.frame
with headers from cat
  # temp <- as.data.frame(t(p$cat))
  temp <- as.data.frame(matrix(rep(NA,nrand*nrow(p)), nrand, nrow(p)))
  names(temp) <- p$cat
  res.nr <- temp[-1,] #empty data.frame with headers from cat
  res.area.mean <- res.nr
  res.area.median <- res.nr
  n <- nrow(d)
}
```

```

# library(doParallel)
# library(foreach)
# registerDoParallel()

d$rand <- runif(n)

# bla <- foreach (j=1:nrand, .combine=rbind, .inorder=F) %dopar% {
for (j in 1:nrand){
  d$rand <- runif(n)
  rand.perc.nr <- quantile(d$rand, probs=c(p$cum.nr))
  for (i in 1:nrow(p)){
    res.nr[j,as.character(p$cat[i])] <- length(d$d$rand >= (if (i==1) 0 else
p$cum.cat[i-1]) & d$rand<p$cum.cat[i],1])
    res.area.mean[j,as.character(p$cat[i])] <- mean(d$area[d$rand >= (if (i==1)
0 else rand.perc.nr[i-1]) & d$rand<rand.perc.nr[i]])
    res.area.median[j,as.character(p$cat[i])] <- median(d$area[d$rand >= (if
(i==1) 0 else rand.perc.nr[i-1]) & d$rand<rand.perc.nr[i]])
  }
}

rankIt <- function(this, rest, selector){
  # if (length(this) != length(selector)) stop("urka!")
  # # rank(c(this[selector], unlist(rest[, selector])))
  # Vectorize(function(x) rank(c(this[x], unlist(rest[, x])))[1])(selector)

  # apply(selector, 1, function(x) rank(c(this[x], unlist(rest[, x])))[1])
  ris <- NULL
  for (i in 1:length(selector)){
    ris <- c(ris, rank(c(this[i], unlist(rest[,
as.character(selector[i])])))[1])
  }
  ris
}

p <- p %>% mutate(rank.nr = rankIt(true.nr, res.nr, cat),
  pval.nr = ((nrand+1)/2 - abs(rank.nr - (nrand+1)/2)) / nrand
*2,
  rank.area.mean = rankIt(true.area.mean, res.area.mean, cat),
  pval.area.mean = ((nrand+1)/2 - abs(rank.area.mean -
(nrand+1)/2)) / nrand *2,
  rank.area.median = rankIt(true.area.median, res.area.median,
cat),
  pval.area.median = ((nrand+1)/2 - abs(rank.area.median -
(nrand+1)/2)) / nrand *2
)

res.nr.summary <- rbind(res.nr %>% summarise_all(length),
  res.nr %>% summarise_all(mean),
  res.nr %>% summarise_all(median),
  res.nr %>% summarise_all(min),
  res.nr %>% summarise_all(max)) %>%
  mutate(var=v)
res.nr.summary$type=paste0('nr.', c('n', 'mean', 'median', 'min', 'max'))

res.nr.summary <- res.nr.summary %>% gather("cat", "value", -var, -type) %>%
spread(type, value)

p <- p %>% left_join(res.nr.summary, by="cat")

write.csv(p, csvFilename)

list(p, res.nr, res.area.mean, res.area.median, res.nr.summary)
}

#####
# Further steps before starting with the simulation
#####

library(readxl)

# Import with source the files and function generated in the two previous r-skript

source('import.r')
source('f_randomizer_dplyr.r')

# p <-
read_xlsx("/Users/Olly/Desktop/R/Rskript_Chiasso/r/Area_Stabio_Chiasso.xlsx")

# Based on the point-shapefile, we calculate the proportion of land use with the
following steps:
# 1) Select all points of the variables ending with '_cat', '_text', '_int',...in
the black locust areas
# 2) gather(): create a list of the variables: gather() takes multiple columns,
and gathers them into key-value pairs -> "it makes wide data longer". This step
was doing for all variables except the variable black locust
# 3) group_by(): Group by variables and category and summarise the number of
points in the individual variables
# 4) Filter the dataframe p and assign the value 0 to the NA
# 5) Final step: group the variables and calculate the proportion of land use
based on the number of points in each variable

p <- d %>% select(robinia, ends_with('_cat'), ends_with('_int'),
ends_with('_text'),
  evol, caduta_sassi, landslide, area_fire) %>% gather('var','cat',
-robinia) %>% group_by(var, cat) %>% summarise(area =n())
p <- p %>% filter(!is.na(cat))
p <- p %>% group_by(var) %>% mutate(pc = area / sum(area, na.rm=T) *100) %>%
ungroup()

```



```
#####
#Starting of the simulation
#####

if (file.exists('randomizations_9999.csv')){
  out <- read_csv('randomizations_9999.csv')
} else {

  l <- list()
  r <- list()

  for (v in c('luc40_cat', 'luc40_int', 'luc40_text', 'luc18_cat', 'luc18_int',
'luc18_text', 'evol', # Land use variables, evolution
'caduta_sassi', 'landslide', 'area_fire',
# Natural hazards
'elevation_cat', 'slope_cat', 'aspect_cat',
# DEM variables
'vignc_n_cat', 'vignc_o_cat',
# Distances from old and new vineyards
'fc_n_cat', 'fc_o_cat',
# Distances from old and new railways
'ssc_n_cat', 'ssc_o_cat', 'spc_n_cat', 'spc_o_cat',
# Distances from old and new roads
'fic_n_cat', 'fic_o_cat')) {
# Distances from old and new rivers

  #Selects the variable used for the simulation

  print(paste0('processing ', v, ' ...'))      # Shows the variable which
have been processed
  # per <- d %>% filter(robinia == 0) %>% select_(var) %>%
  # group_by_(var) %>% summarize(n = n()) %>% mutate(pc =
n/sum(n)*100) %>%
  # rename_(cat=var, area='n') # %>% mutate(cat = paste0("C",cat))
  per <- p %>% filter(tolower(var)==tolower(v)) %>% select(-1)

  dr <- d %>% filter(robinia == 1) %>% rename_(cat=v) %>% mutate(area=0)#, #
filter d, hold only points where black locust is present (=1)
  # cat = paste0("C",cat))

  res <- randomizeFires(dr, per, 9999, paste0('out_',v, '.csv')) # Defines
the numer of simulation, in this case 9999 and what to take for the simulation,
e.g. dr, per. The output of the single simulation for the different variables are
resume in a single table

  res[[1]]$var <- v
  res[[2]]$var <- v

  l[[v]] <- res[[1]]

```

```

r[[v]] <- res[[5]]

  #write_csv(res[[5]], paste0('prova2_rand_', v, '.csv'))
}

out <- do.call(rbind, l)

  write_csv(out, 'randomizations_9999_18.6_strade principali.csv') # Name of
the output file 'randomizations_Nr.of simulation_date'
}

#####
# Plot generation
#####

# The library "devtools" permits to be able to install library generate by other
users
# Instead, install_github ('') permits me concretly to install a library generate
by Boris Pezzatti
# This comandns have only to be executed once! Then i can put #

#library(devtools)
#install_github('pezzacolori/boris-r-misc')

source('do.r') # install th results and outputs of the skript 'do.r'
out1 <- read_xlsx('randomizations_9999_chiasso_18.6.xlsx')

dd <- d %>% gather("variable", "value", aspect_cat, elevation_cat, slope_cat,
evol, spc_o_cat,
                    spc_n_cat, ssc_o_cat, ssc_n_cat, fic_n_cat, fic_o_cat,
vignc_o_cat, vignc_n_cat)

# With the function ggplot i generate different plot and assign it a name with
ggsave

ggplot(dd, aes(x=factor(robinia), y=value)) +
  geom_boxplot() +
  facet_grid(variable ~ ., scales="free")
ggsave('bx_continuous.pdf', w=6, h=20)

ggplot(dd, aes(x=value)) +
  geom_histogram(stat="count") +
  facet_grid(robinia ~ variable, scales="free")
ggsave('bx_continuous_histogram5.pdf', w=20, h=5)

# I compute the different interested metrics for the different variables and i add
it to output file

out1 <- out1 %>% mutate(pval.nr.cat = cut(pval.nr, c(0, 0.001, 0.01, 0.05, 1),
labels=c('***', '**', '*', 'n.s.'), include.lowest=T),

```

```

pcc.nr.min = nr.min / 2567 * 100,
pcc.nr.max = nr.max / 2567 * 100,
pcc.cat = pc.cat * 100,
pcc.nr = pc.nr * 100)

# Generation of the dataframe ddd -> from the table out1 imported previously ->
select...and add columns with new names

ddd <- out1 %>% select(var, cat, pcc.cat, pcc.nr, pcc.nr.min, pcc.nr.max) %>%
  rename(simulation=pcc.cat, 'black locust'=pcc.nr, min=pcc.nr.min,
max=pcc.nr.max) %>%
  gather('reference', 'value', simulation, 'black locust')

ggplot(ddd, aes(x=cat, y=value, fill=reference))+
  geom_bar(stat='identity', position='dodge') +
  facet_wrap(~var, scales="free")

# Generation of the dataframe ddd2 -> based on the table out1 -> select...and add
columns with new names

ddd2 <- out1 %>% select(var, cat, pcc.cat, pcc.nr,pval.nr.cat, pcc.nr.min,
pcc.nr.max) %>%
  rename(simulation=pcc.cat, 'black locust'=pcc.nr, pval = pval.nr.cat,
min=pcc.nr.min, max=pcc.nr.max) %>%
  gather('reference', 'value', simulation, 'black locust')

ddd2$pval[ddd2$reference=='simulation'] <- NA
ddd2$min[ddd2$reference!='simulation'] <- NA
ddd2$max[ddd2$reference!='simulation'] <- NA

# install the library of Boris Pezzatti "orderfactor" which permits to ordinate
variables

library(boris)
ddd2 <- ddd2 %>% mutate(cat4col = ifelse(reference=='simulation', reference,
as.character(pval)),
  cat4col2 = orderfactor(factor(cat4col), c(5,3,2,1,4)))

# generate a plot with all variables used in the MCS (not ordered)

ggplot(ddd2, aes(x=cat, y=value, fill=cat4col2, ymin = min, ymax=max))+
  geom_bar(stat='identity', position='dodge', width = 0.9) +
  geom_errorbar(stat='identity', position=position_dodge(0.9), width=0.2) +
  facet_wrap(~var, scales="free", ncol=4) +
  scale_fill_manual(values=c('grey30', 'red4', 'orangered2', 'orange1', 'grey80'))
+
  theme(axis.text.x = element_text(angle=60, hjust=1,vjust=1))

ggsave('plotMteCarlo_all.pdf', w=14, h=20)

```

# Generation of a list with the variables which wanted to be plot, and reordinate categories on the right side

```

conf <- list()
conf[['evol']] <- c(3,2,1,4:7)
conf[['luc40_cat']] <- c(1,8:14,2:7)
conf[['luc40_text']] <- c(1,8:14,2:7)
conf[['luc40_int']] <- c(1,2,3,4)
conf[['luc18_cat']] <- c(1,2,9:12,3:8)
conf[['luc18_text']] <- c(1,8:14,2:7)
conf[['luc18_int']] <- c(1,2,3,4)
conf[['spc_o_cat']] <- c(2,4,5,3,1)
conf[['spc_n_cat']] <- c(2,4,5,3,1)
conf[['ssc_n_cat']] <- c(2,4,5,3,1)
conf[['ssc_o_cat']] <- c(2,4,5,3,1)
conf[['vignc_n_cat']] <- c(2,3,5,6,4,1)
conf[['vignc_o_cat']] <- c(2,3,5,6,4,1)
conf[['fic_n_cat']] <- c(1,3,2)
conf[['fic_o_cat']] <- c(2,5,3,4,1)
conf[['fc_n_cat']] <- c(2,5,3,4,1)
conf[['fc_o_cat']] <- c(2,5,3,4,1)
conf[['aspect_cat']] <- c(1,4,2,3)
conf[['elevation_cat']] <- c(1,2,3,4)
conf[['slope_cat']] <- c(1,2,3,4)
conf[['area_fire']] <- c(1,2)
conf[['caduta_sassi']] <- c(1,2)
conf[['landslide']] <- c(1,2)

```

```

text45 <- list()
text45[['evol']] <- F
text45[['luc40_cat']] <- F
text45[['luc40_text']] <- T
text45[['luc18_cat']] <- F
text45[['luc18_text']] <- T
text45[['spc_o_cat']] <- F
text45[['spc_n_cat']] <- F
text45[['ssc_n_cat']] <- F
text45[['ssc_o_cat']] <- F
text45[['vignc_n_cat']] <- F
text45[['vignc_o_cat']] <- F
text45[['fic_n_cat']] <- F
text45[['fic_o_cat']] <- F
text45[['fc_n_cat']] <- F
text45[['fc_o_cat']] <- F
text45[['aspect_cat']] <- F
text45[['elevation_cat']] <- F
text45[['slope_cat']] <- F

```

```

library(grid)
library(gridExtra)

```

```

#scale_fill_brewer(palette = "YlOrBr", drop=F)

#install.packages("wesanderson")
#library(wesanderson)

# For each variable present in ddd2, a plot is generated. Additionally, an error
bar is added to each category

ddd3 <- ddd2[-c(19:32, 49:60, 154:167, 184:195), ]

l <- list()

for (v in unique(ddd3$var)[1:21]) { #Specify the order of the variables in
[1:23] [8,9,13,10,11,12,15,14,17,16,23,22,21,20,19,18, 2,5,8,1,4,3,6]
  x <- ddd3 %>% filter(var==v)
  if (! is.null(conf[[v]])){
    x <- x %>% mutate(cat = orderfactor(factor(cat), conf[[v]]))
  }
  if (is.null(text45[[v]])){
    an=0
    ju=0.5
  }else{
    an <- ifelse(text45[[v]], 45, 0)
    ju <- ifelse(text45[[v]], 0, 0.5)
  }

  l[[v]] <- ggplot(x, aes(x=cat, y=value, fill=cat4col2, ymin = min, ymax=max),
droplevels=F)+
  geom_bar(stat='identity', position='dodge', width = 0.9) +
  theme(legend.title=element_blank()+
xlab(v) +ylab("") +
  theme(axis.text.x = element_text(angle=an, hjust = ju, vjust = ju)) +

  # ylab("Frequency of black locust") +
  #facet_wrap(~var, scales="free", ncol=4) +
  geom_errorbar(stat='identity', position=position_dodge(0.9), width=0.2) +
  scale_fill_manual(values=c('grey30', 'red4', 'orangered2', 'orange1',
'grey80'), drop=F)
  #scale_fill_brewer(palette = "YlOrBr", drop=F)

  # ggsave(paste0("plotMteCarlo_",v, ".jpg"))
  # ggsave(paste0("plotMteCarlo_",v, ".jpg"), w=9.5, h=6)
}

# grid.arrange(grobs=l, ncol = 4, main = "Main title")
grid_arrange_shared_legend(l, ncol = 3, nrow=7)

```

```

#####
# Generation of the common legend for the Monte Carlo Plots
#####

library(grid)
library(gridExtra)

grid_arrange_shared_legend <- function(plots, ncol = length(list(...)), nrow = 1,
position = c("bottom", "right")) {

  position <- match.arg(position)
  g <- ggplotGrob(plots[[1]] + theme(legend.position = position))$grobs
  legend <- g[[which(sapply(g, function(x) x$name) == "guide-box")]]
  lheight <- sum(legend$height)
  lwidth <- sum(legend$width)
  gl <- lapply(plots, function(x) x + theme(legend.position="none"))
  gl <- c(gl, ncol = ncol, nrow = nrow)

  combined <- switch(position,
    "bottom" = arrangeGrob(do.call(arrangeGrob, gl),
      legend,
      ncol = 1,
      heights = unit.c(unit(1, "npc") -
lheight, lheight)),
    "right" = arrangeGrob(do.call(arrangeGrob, gl),
      legend,
      ncol = 2,
      widths = unit.c(unit(1, "npc") -
lwidth, lwidth)))
  grid.newpage()
  grid.draw(combined)

  # return gtable invisibly
  invisible(combined)
}

#####
#This r-skript contains the steps to generate the input file for the further model
generation
#####

# with source i import everithing present in the skript import.r

source('import.r')

# Read the shapefile (dbf.) of the three study areas (Sementina, Chiasso, Stabio)
sementina <- read.dbf("/Users/Olly/Desktop/R/laetitia/gis/Final_Sementina2.dbf",
T)

```

```

chiasso <-
read.dbf("/Users/Olly/Desktop/R/Rskript_Chiasso/gis/Final_Chiasso2.dbf", T)
stabio <- read.dbf("/Users/Olly/Desktop/R/Rskript_Stabio/gis/Final_Stabio2.dbf",
T)

names(sementina) <- tolower(names(sementina))
names(chiasso) <- tolower(names(chiasso))
names(stabio) <- tolower(names(stabio))

# Re-calculation of the land use evolution

chiasso <- chiasso %>% mutate(evol = luc18_int - luc40_int)
sementina <- sementina %>% mutate(evol = lu17_inten - lu43_inten)
stabio <- stabio %>% mutate(evol = lus18_int - lus40_int)

unique((sementina[, c("lu17_cat", "lu17_text")]))
unique((sementina[, c("lu43_cat", "lu43_text")]))

# Add a column to the dataframe with a site_id (1 = Chiasso, 2 = Stabio, 3 =
Sementina)

chiasso <- chiasso %>% mutate(site_id = 1)
stabio <- stabio %>% mutate(site_id = 2)
sementina <- sementina %>% mutate(site_id = 3)

# Change the name of the columns with the function "names"

# sementina
names(sementina)

names(sementina)[names(sementina)=="lu43_inten"] <- "lu40_int"
names(sementina)[names(sementina)=="lu17_inten"] <- "lu18_int"
names(sementina)[names(sementina)=="lu17_cat"] <- "lu18_cat"
names(sementina)[names(sementina)=="lu43_cat"] <- "lu40_cat"
names(sementina)[names(sementina)=="lu43_text"] <- "lu40_text"
names(sementina)[names(sementina)=="lu17_text"] <- "lu18_text"
names(sementina)[names(sementina)=="vigne_43_d"] <- "vigne_o_d"
names(sementina)[names(sementina)=="vigne_17_d"] <- "vigne_n_d"
names(sementina)[names(sementina)=="str_09_v"] <- "sp_o_d"
names(sementina)[names(sementina)=="str_09_n"] <- "sp_n_d"
names(sementina)[names(sementina)=="str101115v"] <- "ss_o_d"
names(sementina)[names(sementina)=="str101115n"] <- "ss_n_d"

names(sementina)

# chiasso
names(chiasso)
names(chiasso)[16] <- "elevation" #rename 'elev_c'
names(chiasso)[17] <- "slope" #rename 'slope_c'
names(chiasso)[15] <- "aspect" #rename 'aspect_c'

```

```

names(chiasso)[14] <- "lu40_int" #rename 'luc40_int'
names(chiasso)[21] <- "lu18_int" #rename 'luc18_int'
names(chiasso)[12] <- "lu40_cat" #rename 'luc40_cat'
names(chiasso)[19] <- "lu18_cat" #rename 'luc18_cat'
names(chiasso)[33] <- "lu40_text" #rename 'luc40_text'
names(chiasso)[32] <- "lu18_text" #rename 'luc18_text'
names(chiasso)[4] <- "vigne_o_d" #rename 'vignc_o_d'
names(chiasso)[3] <- "vigne_n_d" #rename 'vignc_n_d'
names(chiasso)[8] <- "sp_o_d" #rename 'spc_o_d'
names(chiasso)[7] <- "sp_n_d" #rename 'spc_n_d'
names(chiasso)[6] <- "ss_o_d" #rename 'ssc_o_d'
names(chiasso)[5] <- "ss_n_d" #rename 'ssc_n_d'
names(chiasso)[9] <- "fiu_o_d" #rename 'fic_o_d'
names(chiasso)[10] <- "fiu_n_d" #rename 'fic_n_d'
names(chiasso)[37] <- "fe_o_d" #rename 'fc_o_d'
names(chiasso)[36] <- "fe_n_d" #rename 'fc_n_d'
names(chiasso)[28] <- "fire_area" #rename 'area_fire'
names(chiasso)[22] <- "cad_sassi" #rename 'area_cs'
names(chiasso)

# stabio
names(stabio)
names(stabio)[15] <- "elevation" #rename 'elev_s'
names(stabio)[14] <- "slope" #rename 'slope_s'
names(stabio)[13] <- "aspect" #rename 'aspect_s'
names(stabio)[21] <- "lu40_int" #rename 'luc40_int'
names(stabio)[18] <- "lu18_int" #rename 'luc18_int'
names(stabio)[19] <- "lu40_cat" #rename 'lus40_cat'
names(stabio)[16] <- "lu18_cat" #rename 'lus18_cat'
names(stabio)[23] <- "lu40_text" #rename 'lus40_text'
names(stabio)[22] <- "lu18_text" #rename 'lus18_text'
names(stabio)[3] <- "vigne_n_d" #rename 'vigns_n_d'
names(stabio)[6] <- "sp_o_d" #rename 'sps_o_d'
names(stabio)[7] <- "sp_n_d" #rename 'sps_n_d'
names(stabio)[4] <- "ss_o_d" #rename 'sss_o_d'
names(stabio)[5] <- "ss_n_d" #rename 'sss_n_d'
names(stabio)[10] <- "fiu_o_d" #rename 'fis_o_d'
names(stabio)[11] <- "fiu_n_d" #rename 'fis_n_d'
names(stabio)[9] <- "fe_n_d" #rename 'fs_n_d'
names(stabio)

```

```

# The dataframe of sementina and stabio need to further be adopted in order to
have a consistent matrix to be utilized for the model generation
# The distance variables not analyzed by Burkhardt(2017) were added as new columns
to the dataframe and compiled by measuring the distances from geo.admin.ch
# New added variables: distances from old/new river, old/new railways
# In stabio, even if the natural hazards were not present, new columns were
generated and assigned the value 0 (because the event was not present)

```

# 999 indicates an approximation, not the real distance from the feature per se. This because we assumes that such a high distance has a low possibility to influence the colonization processes of black locust

```
sementina <- sementina %>% mutate(fiu_o_d = 999,
                                fiu_n_d = 999,
                                fe_o_d = 999,
                                fe_n_d = 999)
```

```
stabio <- stabio %>% mutate(fe_o_d = 999,
                           vigne_o_d = 999,
                           fire_area = 0,
                           cad_sassi = 0)
```

# For the variables related to the land use, i need to made the land use categories utilized in Burkhardt(2017) consistent with the one utilized in this master thesis. The variables needed to be adapted are: lu43\_cat, lu43\_text, luc40\_cat, luc40\_text, luc18\_cat, luc18\_text

# To convert the land use categories into new one, i create a conversion\_map (basically a new data.frame) with two columns:  
 # 1) Number of the old land use categories of Burkhardt(2017)  
 # 2) Numebr of the new land use categories which correspond to one utilized in the master thesis  
 # (old -> cat\_vecchia, new -> cat\_nuova)

```
conversion_map <- tribble( ~old,~new,
  1, 4,
  2, 12,
  3, 13,
  4, 14,
  5, 15,
  6, 9,
  7, 0,
  8, 1,
  9, 19,
  10, 3,
  11, 5,
  12, 2,
  13, 20,
  14, 10,
  15, 21)
```

# I create a new column (lu40\_cat\_n, new) in the data.frame "sementina" and i replace the categories of the column lu40\_cat with the new category number with the previously created conversion map

```
sementina <- sementina %>% mutate(lu40_cat_n =
  conversion_map[conversion_map$old==lu40_cat, 'new'])
```

```
sementina$lu40_cat_n <- sapply(sementina$lu40_cat, function(x) {
  temp <-
  conversion_map$new[conversion_map$old==x & !is.na(x)]
  if (length(temp)==0)
  NA else temp[1]
})
```

# The same was done for the variable lu18\_cat

```
sementina <- sementina %>% mutate(lu18_cat_n =
  conversion_map[conversion_map$old==lu18_cat, 'new'])

sementina$lu18_cat_n <- sapply(sementina$lu18_cat, function(x) {
  temp <-
  conversion_map$new[conversion_map$old==x & !is.na(x)]
  if (length(temp)==0)
  NA else temp[1]
})
```

#...and the variable ending with '\_text' of Sementina (lu40\_text e lu18\_text).  
 # However, a new conversion map need to be created

```
conversion_map_text_40 <- tribble( ~old,~new,
  'built area and roads', 'Area urbana',
  'coppice type 1', 'Bosco ceduo 1',
  'coppice type 2', 'Bosco ceduo 2',
  'coppice type 3', 'Bosco ceduo 3',
  'coppice type 4', 'Bosco ceduo 4',
  'riparian forests', 'Bosco ripariale',
  'vineyards with houses', 'Vigneti con casetta',
  'vineyards', 'Vigneti',
  'abandoned vineyards', 'Vigneti abbandonati',
  'grassland and other landuses', 'Prati ed altri
  utilizzi',
  'field crop area', 'Campi coltivati',
  'mixed agricultural area', 'Area agricola',
  'modern houses with garden', 'Case moderne con
  giardini',
  'river', 'Fiume',
  'frana', 'Frana')
```

# lu40\_text sementina

```
sementina <- sementina %>% mutate(lu40_text_n =
  conversion_map_text_40[conversion_map_text_40$old==lu40_text, 'new'])

sementina$lu40_text_n <- sapply(sementina$lu40_text, function(x) {
```

```

conversion_map_text_40$new[conversion_map_text_40$old==x & !is.na(x)]
NA else temp[1]
    temp <-
    if (length(temp)==0)
    }
)

# lu18_text sementina

conversion_map_text_18 <- tribble( ~old,~new,
  'built area and roads', 'Area urbana',
  'coppice type 1', 'Bosco ceduo 1',
  'coppice type 2', 'Bosco ceduo 2',
  'coppice type 3', 'Bosco ceduo 3',
  'coppice type 4', 'Bosco ceduo 4',
  'riparian forests', 'Bosco ripariale',
  'vineyards with houses', 'Vigneti con casetta',
  'vineyards', 'Vigneti',
  'abandoned vineyards', 'Vigneti abbandonati',
  'grassland and other landuses', 'Prati ed altri
utilizzi',
  'field crop area', 'Campi coltivati',
  'mixed agricultural area', 'Area agricola',
  'modern houses with garden', 'Case moderne con
giardini',
  'river', 'Fiume',
  'frana', 'Frana')

sementina <- sementina %>% mutate(lu18_text_n =
conversion_map_text_18[conversion_map_text_18$old==lu18_text, 'new'])

sementina$lu18_text_n <- sapply(sementina$lu18_text, function(x) {
  temp <-
  conversion_map_text_18$new[conversion_map_text_18$old==x & !is.na(x)]
  if (length(temp)==0)
  NA else temp[1]
})

# Now the dataframe of sementina contains the columns lu40_cat_n and lu18_cat_n
with the new categories;
# and the columns lu40_text_n and lu18_text_n with the new names (description of
the categories)
# Next step: remove the columns with the old land use categories: lu40_cat,
lu18_cat, lu40_text, lu18_text and rename the other (lu40_cat_n,
lu18_cat_n,lu40_text_n, lu18_text_n)

sementina$lu40_cat <- NULL
sementina$lu18_cat <- NULL
sementina$lu40_text <- NULL

```

```

sementina$lu18_text <- NULL
#sementina$elettrodot <- NULL

names(sementina)
names(sementina)[names(sementina)=="lu40_cat_n"] <- "lu40_cat" #rename
'lu40_cat_n'
names(sementina)[names(sementina)=="lu18_cat_n"] <- "lu18_cat" #rename
'lu18_cat_n'
names(sementina)[names(sementina)=="lu40_text_n"] <- "lu40_text" #rename
'lu40_text_n'
names(sementina)[names(sementina)=="lu18_text_n"] <- "lu18_text" #rename
'lu18_text_n'

# Variable fire in Sementina: i need to merge all the column of fire_id in order
to have only one with the values 0 and 1
# PrVIOUS to this step, i need to assign the values 0, 1 to the fire_id_columns
# Then, with the function coalesce() i merge all the columns of fire_id in an
individual one

sementina <- sementina %>% mutate(fire_id_01 = ifelse(fire_id_01 > 0, 1, 0),
  fire_id_02 = ifelse(fire_id_02 > 0, 1, 0),
  fire_id_03 = ifelse(fire_id_03 > 0, 1, 0),
  fire_id_04 = ifelse(fire_id_04 > 0, 1, 0))

chiasso <- chiasso %>% mutate(fire_area = ifelse(fire_area > 0, 1, 0))

sementina <- sementina %>% mutate(fire_area = coalesce(sementina$fire_id_01,
  sementina$fire_id_02,
  sementina$fire_id_03,
  sementina$fire_id_04))

# Remove the unnecessary variable over all three study sites

dim(sementina)
dim(chiasso)
dim(stabio)

#chiasso$colonna what should be removed <- NULL

sementina$fire_id_01 <- NULL
sementina$fire_id_02 <- NULL
sementina$fire_id_03 <- NULL
sementina$fire_id_04 <- NULL

chiasso$cid <- NULL
chiasso$new_id <- NULL
chiasso$luc40_area <- NULL
chiasso$near_dist <- NULL
chiasso$near_fid <- NULL
chiasso$luc18_area <- NULL

```

```

chiasso$area <- NULL
#chiasso$presen_cs <- NULL
chiasso$area_cs <- NULL
chiasso$year <- NULL
chiasso$presen_ls <- NULL
chiasso$area_ls <- NULL
chiasso$fire_id <- NULL
chiasso$fire_id_01 <- NULL
chiasso$fire_id_02 <- NULL
chiasso$fire_id_03 <- NULL
dim(chiasso)

stabio$cid <- NULL
stabio$new_id <- NULL
stabio$sas_o_d <- NULL
stabio$lus18_area <- NULL
stabio$lus40_area <- NULL
stabio$near_fid <- NULL
stabio$near_dist <- NULL
stabio$vigns_n_cat <- NULL
stabio$sss_o_cat <- NULL
stabio$sss_n_cat <- NULL
stabio$sps_n_cat <- NULL
stabio$sps_o_cat <- NULL
stabio$sas_o_cat <- NULL
stabio$fs_n_cat <- NULL
stabio$fis_n_cat <- NULL
stabio$fis_o_cat <- NULL
stabio$elevation_cat <- NULL
stabio$slope_cat <- NULL
stabio$aspect_cat <- NULL
dim(stabio)

sementina$cid <- NULL
sementina$near_fid <- NULL
sementina$near_dist <- NULL
sementina$join_count <- NULL
sementina$orig_fid <- NULL
sementina$fid_1 <- NULL
sementina$target_fid <- NULL
sementina$id <- NULL
sementina$presenza <- NULL
sementina$area <- NULL

## final steps: replace the names of some variables, and remove the unnecessary one
names(sementina)[names(sementina)=="id_rob"] <- "id_polygon"      #rename columns
'id_rob'
names(sementina)[names(sementina)=="area_rob"] <- "area_polygon"  #rename
columns 'area_rob'

names(chiasso)[names(chiasso)=="area_rob"] <- "area_polygon"      #rename columns
'area_rob'
names(stabio)[names(stabio)=="area_robs"] <- "area_polygon"      #rename columns
'area_robs'

stabio$area_polyg <- NULL
chiasso$area_polyg <- NULL
sementina$new_id <- NULL

dim(sementina)
dim(chiasso)
dim(stabio)

# Final step, with the function 'bind_rows' i bind together all rows over the
three study areas, generating the final matrix

Final_matrix_new2 <- bind_rows(chiasso, stabio, sementina)

write.csv(Final_matrix_new2, file = "Final_matrix_new2.csv")
write.csv(Final_matrix_new2, file = "Final_matrix_all_anne.csv")

#####
# Results of MaxEnt Model
#####

# Load the data with the result of the MaxEnt with the best AUC overall the three
study sites

library(tidyverse)
library(foreign)

MaxEnt_all_areas <-
read.csv("/Users/Olly/Desktop/R/robinia4olivia/all/robinia_data_auc.bg.csv", T)

MaxEnt_Chiasso <- read.dbf("/Users/Olly/Desktop/R/robinia4olivia/all/Study
Area/Robinia_data_auc_Chiasso.dbf", T)

MaxEnt_Stabio <- read.dbf("/Users/Olly/Desktop/R/robinia4olivia/all/Study
Area/Robinia_data_auc_Stabio.dbf", T)

MaxEnt_Sementina <- read.dbf("/Users/Olly/Desktop/R/robinia4olivia/all/Study
Area/Robinia_data_auc_Sementina.dbf", T)

# Do a sample of a random number of points. Once with presence == 1 and once
presence == 0 to then generate boxplots for each study site

MaxEnt_Chiasso_Rob <- MaxEnt_Chiasso %>% filter(presence == 1)
MaxEnt_Chiasso_noRob <- MaxEnt_Chiasso %>% filter(presence == 0)

```

```

MaxEnt_Stabio_Rob <- MaxEnt_Stabio %>% filter(presence ==1)
MaxEnt_Stabio_noRob <- MaxEnt_Stabio %>% filter(presence == 0)

MaxEnt_Sementina_Rob <- MaxEnt_Sementina %>% filter(presence == 1)
MaxEnt_Sementina_noRob <- MaxEnt_Sementina %>% filter(presence == 0)

MaxEnt_all_areas_Rob <- MaxEnt_all_areas %>% filter(presence == 1)
MaxEnt_all_areas_noRob <- MaxEnt_all_areas %>% filter(presence == 0)

## sample

n = 1000

all_sample <- bind_rows(bind_cols(site=rep('Chiasso', n), robinia=rep(1, n),
MaxEnt_Chiasso_Rob %>% sample_n(n, replace=F) ),
                        bind_cols(site=rep('Chiasso', n), robinia=rep(0, n),
MaxEnt_Chiasso_noRob %>% sample_n(n, replace=F) ),
                        bind_cols(site=rep('Stabio', n), robinia=rep(1, n),
MaxEnt_Stabio_Rob %>% sample_n(n, replace=F) ),
                        bind_cols(site=rep('Stabio', n), robinia=rep(0, n),
MaxEnt_Stabio_noRob %>% sample_n(n, replace=F) ),
                        bind_cols(site=rep('Sementina', n), robinia=rep(1, n),
MaxEnt_Sementina_Rob %>% sample_n(n, replace=F) ),
                        bind_cols(site=rep('Sementina', n), robinia=rep(0, n),
MaxEnt_Sementina_noRob %>% sample_n(n, replace=F) )
)

all_sample <- bind_rows(all_sample,
                        all_sample %>% mutate(site='all sites'))

## Boxplot

at <- c(1.2,1.8, 3.2,3.8, 5.2, 5.8, 7.2, 7.8)
atmid <- c(1.5,3.5,5.5, 7.5)

b <- boxplot(maxent ~ robinia * site, data=all_sample,
             boxwex=0.4,
             notch=T,
             outline=F,
             at=at,
             ylab = "MaxEnt predicted value",
             col = rep(c('white', 'grey'), 4),
             xaxt='n')
text(x=atmid, y=0.99, labels = rep('***',4), cex=0.8)
mtext('n =', 3, at=0.5, cex=0.8, font=3, line=0.4)
mtext(b$n, 3, at=at, cex=0.8, font=3, line=0.4)
axis(1, at=at, labels=c(0,1,0,1,0,1, 0,1))
mtext(side=1, at=atmid, text=c('all sites', 'Chiasso', 'Sementina', 'Stabio'),
line=2.6)

abline(v=2.5)

# Wilcoxon test in R

wilcox_chiasso <- wilcox.test(maxent ~ robinia, data = all_sample %>% filter(site
=='Chiasso'), alternative = "two.sided", conf.int = TRUE)

wilcox_stabio <- wilcox.test(maxent ~ robinia, data = all_sample %>% filter(site
=='Stabio'), alternative = "two.sided", conf.int = TRUE)

wilcox_sementina <- wilcox.test(maxent ~ robinia, data = all_sample %>%
filter(site =='Sementina'), alternative = "two.sided", conf.int = TRUE)

```

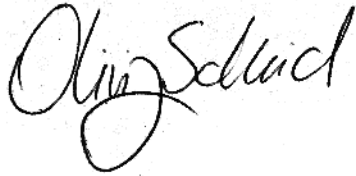


## Personal declaration

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

Olivia Schmid

Cadenazzo, 21.09.2018

A handwritten signature in black ink, reading "Olivia Schmid". The signature is written in a cursive style with a large, looping initial "O" and a long, sweeping underline.