The chestnut needs its master

The revitalisation of Corsica's endangered chestnut agroforestry system

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Niek Pepels

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Name student: Niek Pepels

Registration code: 970619647010

Email: p.niek@live.nl

Course code: FSE-80436

Period: January 2020 – July 2020

Supervisors:

- Kees van Veluw - Wageningen University & Research (*Farming Systems Ecology Group)*
- Emmanuel Guisepelli - Institut Supérieur d'Agriculture Rhône-Alpes (*Department of Social Sciences)*

Examiner:
Ichsani Wheeler – Wageningen University & Research (*Farming Systems Ecology Group)*

The chestnut needs its master - The revitalisation of Corsica's endangered chestnut agroforestry system

Niek Pepels[ab]
[a] Wageningen University & Research, the Netherlands
[b] Institut Supérieur d'Agriculture Rhône-Alpes, France

Abstract

Industrial agriculture is associated with numerous ecological challenges. Therefore, there is a growing scientific interest in alternative agricultural systems such as agroforestry. This research focused on Corsica's chestnut agroforestry system, an agroforestry system that has produced staple food products made from chestnuts for centuries while conserving biodiversity, preventing erosion and sequestering carbon. However, around a century ago, Corsica's chestnut orchards started to be abandoned and the production declined substantially. In 2018, the production was only around 0.11% of what it used to be in 1925, and most orchards were abandoned. The objective of this research was to investigate what is needed to revitalise the abandoned chestnut orchards. Using a case study approach, three different aspects (ecological, social-cultural, political-economic) that impact the restoration of abandoned chestnut orchards were investigated. Desk research and a literature review were conducted to investigate these different aspects and to prepare semi-structured interviews which were conducted with seven Corsican chestnut farmers and nine other actors from different backgrounds, all knowledgeable about the restoration of abandoned chestnut orchards, to understand the local place-shaping processes that influence the restoration of abandoned chestnut orchards. Results show that numerous ecological problems have a strong influence on the health and the production of abandoned chestnut trees. Without human intervention, the combination of ecological problems will kill most abandoned chestnut trees in the coming decades. However, human intervention (pruning, biological control, fencing of the chestnut orchards) can control most ecological problems and is crucial to safe the abandoned chestnut trees. However, there is a lack of Corsicans willing to restore chestnut orchards due to social-cultural problems such as difficult access to land and political-economic problems such as the lack of income, as it takes years for the chestnut trees to become productive after the initial restoration of the orchard. To overcome these hurdles, three promising solutions were identified: 1) make abandoned chestnut orchards available to new farmers (for example by communalising orchards), 2) make more financial resources available to stimulate new farmers and non-farming owners of abandoned chestnut orchards to restore the chestnut orchards, 3) stimulate diversification of the chestnut orchard to enhance the farmer's livelihood resilience and to enable farmers to generate an income in the first years after the restoration of an orchard. Lastly, because of the involvement of several different actors in the restoration of abandoned chestnut orchards, several different visions (large-scale farms versus small-scale farms, financial support of professional chestnut farmers only versus financial support of non-farming owners of abandoned chestnut orchards) prevailed about how to achieve a large-scale restoration. However, the severity of the ecological problems threatening the future of the abandoned chestnut trees requires a coordinated and collaborative approach from a diversity of stakeholders and therefore, the involvement of all actors willing to help restore abandoned orchards should be encouraged to achieve a large-scale restoration.

Keywords: agroforestry, chestnut, chestnut blight, chestnut gall wasp, Corsica, diversification, land transmission

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1. Introduction

1.1 Agroforestry as sustainable alternative to industrial agriculture

Industrial agriculture lies at the heart of several important ecological problems, such as soil degradation and the global biodiversity crisis that threaten both the natural capital of the Earth and the future of humanity, according to the most recent IPBES global assessment report (Díaz *et al.*, 2020). Land-use change (most importantly the conversion of natural ecosystems such as tropical rainforest into industrial agriculture) has been identified as the main culprit for the negative effects on nature caused by humans since the 1970s (Díaz *et al.*, 2020). Because humans are directly and indirectly dependent on the proper functioning of ecosystems to provide their basic needs (food, water, clean air, medicine), alternative agricultural systems are being investigated to produce our food in ways that maintain, rather than reduce, a wide variety of ecosystem services (Stoate *et al.*, 2009; Wezel *et al.*, 2014). Examples of such alternative practices or systems are agroecology, organic agriculture, permaculture and agroforestry. These systems and practices show promise to produce food while also providing important ecosystem functions normally mostly provided by natural ecosystems and only sparsely provided by industrial agricultural systems (Jose, 2009; Wezel *et al.*, 2014).

This research focused on one of Europe's oldest agroforestry systems: the chestnut agroforestry system of Corsica. Agroforestry is defined by the Food and Agriculture Organisation (FAO) as:

> *"a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels"* (FAO, 2015, para. 1).

Environmental benefits linked to agroforestry are higher biodiversity, higher carbon sequestration and lower (chemical) input requirements compared to annual industrial agricultural systems (Jose, 2012; Mosquera-Losada *et al.*, 2012; Nair, 2012; Toensmeier, 2016).

1.2 Corsica's former thriving chestnut civilisation

The Corsican chestnut agroforestry system is grounded on the sweet chestnut *(Castanea sativa)* tree. A typical chestnut orchard (hereafter referred to as "*castagnetu"*, the Corsican word) consists of chestnut trees with herbs growing underneath the trees. Sometimes, the understory is grazed by sheep, goat or pigs (Perry, 1984; Smith, 2013).

The chestnut has been one of Corsica's most important agricultural crops for centuries, especially in the mountainous regions of the island, where the chestnut trees dominated the land around the villages and where cereals could not be cultivated due to the natural constraints imposed by the steep land. The chestnut tree is often called "*bread tree*" because chestnut flour was made from the dried chestnuts and constituted the staple food ingredient for the inhabitants of many of Corsica's mountainous areas where cereal production was not possible (Michon, 2011).

Until the start of the 20th century, inhabitants from Corsica's most densely populated mountainous regions consumed around 500 to 600 grams of chestnut bread or 400 to 500 grams of chestnut polenta each day (Institut National de l'Origine et de la Qualité, 2008). This means that chestnuts provided 1250 to 1500 calories person^{-1} day^{-1} (Institut National de l'Origine et de la Qualité, 2008) which is remarkable considering that almost all the land where the chestnut was cultivated is considered “marginal land” because the steep land does not allow the cultivation of annual cereals.

Another illustration of the importance of the chestnut is the area of land devoted to the chestnut. At its peak around the beginning of the 20th century, the castagnetu covered around 35 000 ha (DRAAF Corse, 2017). Especially in the Corsican microregion *“Castagniccia”* in the north-east of the island, this chestnut agroforestry system fuelled a thriving civilisation supporting population densities between 63 (San Roman Sanz *et al.*, 2013) and 140 inhabitants km^{-2} (Michon, 2011) around 1850, which is more than the current average population density of France which is 122 inhabitants km^{-2} (Statista, 2017). In certain valleys such as the Orezza valley in the heart of Castagniccia, 99% of all cultivable land was devoted to the cultivation of chestnuts (Perry, 1984).

1.3 The collapse of the chestnut civilisation

However, beginning around the beginning of the 20th century, when 35 000 ha of castagnetu were present in Corsica (DRAAF Corse, 2017), the chestnut civilisation started to collapse rapidly due to an interplay between socio-economic (such as rural depopulation because of WWI and WWII) and ecological processes (arrival of chestnut blight, chestnut ink disease and the chestnut gall wasp) which are detailed in **Appendix A** (Michon, 2011; Perry, 1984).
In a matter of several decades, most castagnetu were abandoned. At the end of WWII, which is responsible for the death of thousands of Corsican men (Geers, 2019), only several hundreds of hectares of castagnetu were harvested, in contrast to the 35 000 ha around the beginning of the 20th century (DRAAF Corse, 2017), and most people had left the chestnut-growing regions (Perry, 1984). Illustrative for this rapid collapse is the case of Felce, a village in Castagniccia; in 1900, this villages had three chestnut mills, 34 chestnut drying houses and twelve ovens. In 1967, they had all disappeared (Perry, 1984).

In line with the decline in area of actively managed and harvested castagnetu, the island’s chestnut production also crashed, but there was a slight delay compared to the abandonment of the orchards, possibly caused by inaccurate administrative work (Perry, 1984). The peak production was estimated to be between 74 052 in 1904 (Perry, 1984) and 95 000 tons in 1925 (Smith, 2013), showing that the peak production was actually achieved when the depopulation and abandonment were already initiated. After WWII, the production sharply decreased in line with the abandonment of the castagnetu and only several hundreds of actively harvested castagnetu remained (Perry, 1984).

However, in the 1970s, a social movement of young Corsicans (*“le riacquistu”)* started to restore abandoned orchards in order to safeguard the future of the chestnut in Corsica (Michon *et al.,* 2011). Thanks to this generation of chestnut farmers, several hundreds of hectares of abandoned castagnetu have been restored and a complete collapse of the chestnut agroforestry system has been prevented. Several years after the initial efforts had begun, 860 ha of castagnetu were in production (in 1988) and this kept increasing to reach 1 280 ha in 2000 (DRAAF Corse, 2017) **(Fig. 1**).
In line with the increased area of managed castagnetu, the production of chestnuts also increased. In 1988, after several years of restoration, the production of chestnuts was 630 tons. The production further increased, reaching 1 480 tons of chestnuts in 2000.

However, during the last 18 years, the production has declined and the increase of restored castagnetu has been slowing. The production of chestnuts has crashed, reaching 107 tons (0.11% of the estimated maximum production of 95 000 tons in 1925) in 2018 as a result of the arrival of the chestnut gall wasp in 2010 which has had a devastating impact on the production of the chestnut trees (**Fig. 1;** DRAAF Corse, 2019**).**

Besides the reduced production observed in the last 18 years, the restoration of abandoned castagnetu has been slowing since 2000; only 90 additional hectares were restored in 18 years to reach a total area of 1 370 ha in 2018 (DRAAF Corse, 2019).

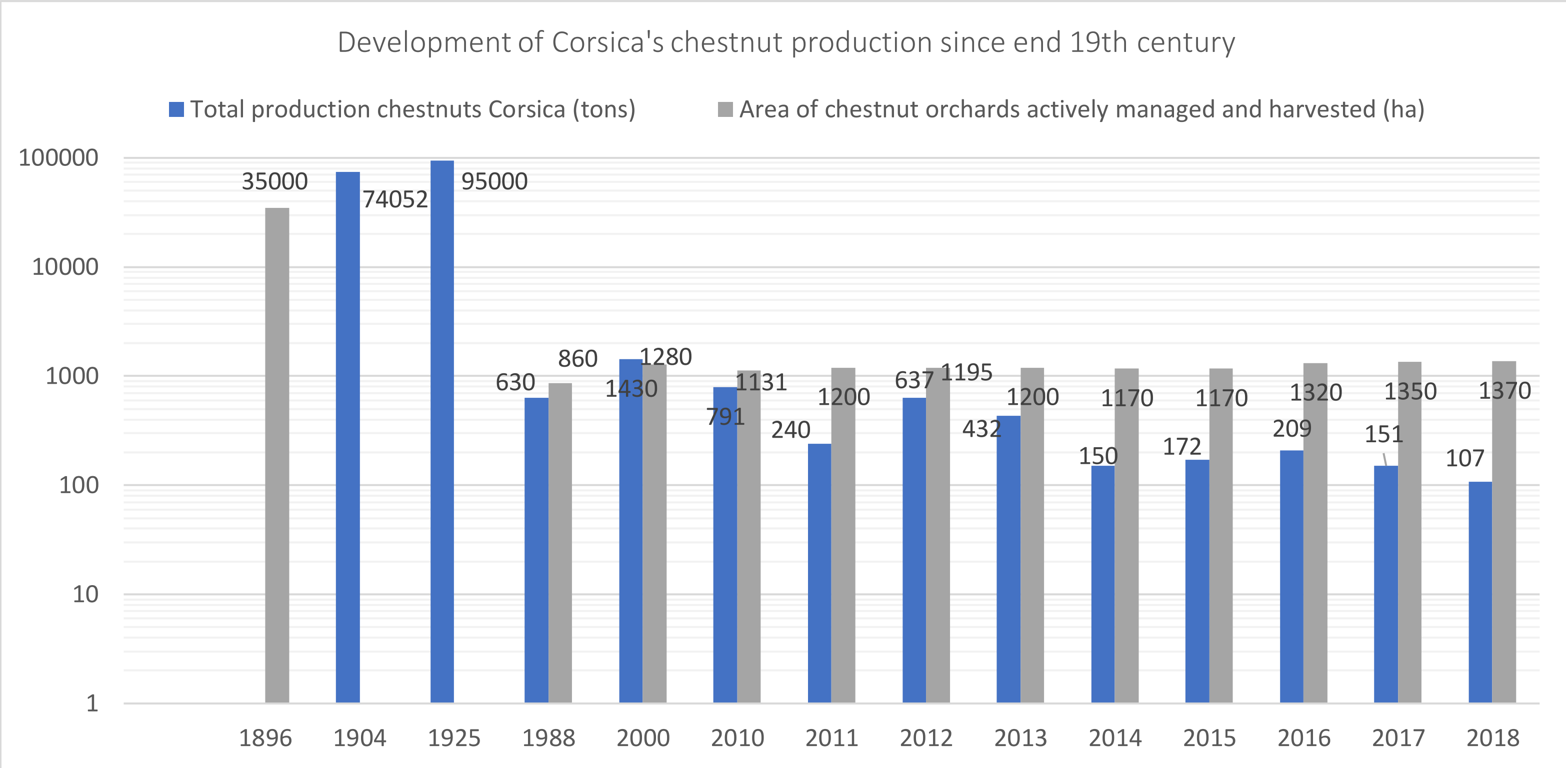

Figure 1. Area of managed and harvested castagnetu and total production since 1896. Note that the y-axis is logarithmic. Sources data: (DRAAF Corse, 2017, 2019; Perry, 1984; Smith, 2013. Note: because of the poor or complete lack of administration from the end of the 19th century to around the 1980s onwards, for the first three years indicated in the graph, only one value (either production or area) was available.

At this moment, only around 80 chestnut farmers are left in Corsica (AOCfarinedechâtaignecorse, 2019a) and most of the formerly exploited castagnetu are currently abandoned. Furthermore, the productivity of both the managed and the abandoned castagnetu is low due to several ecological problems (such as the chestnut gall wasp, mentioned above) which will be introduced in more detail later (Kruslin, 2017).

Still, despite the collapse of the chestnut civilisation, the chestnut represents an important agricultural product for Corsica these days from an economic point of view, and a very important agricultural product from a cultural point of view. When comparing the area of different Corsican crops in 2018 (DRAAF Corse, 2019a), it becomes clear that the total area of actively managed and harvested castagnetu is relatively high compared to other Corsican agricultural products even though most castagnetu are currently abandoned.

Table 1. The area of agricultural land in different crops in Corsica. Source: DRAAF Corse (2019a).

Crop	Area (ha)
Grapevine	5 884
Olive	2 150
Chestnut	1 350
Vegetable	445
Kiwi	323
Peach	162
Hazelnut	155
Apricot	57

1.4 Objectives

An estimated 25 000 to 30 000 ha of abandoned castagnetu that could be restored are left in Corsica but because of a combination of ecological threats (such as the chestnut gall wasp and two fungal diseases, chestnut blight and ink disease, shortly mentioned), it is expected that most abandoned chestnut trees will perish in the coming decades without human intervention (DRAAF Corse, 2017; Kruslin, 2017; Luciani, 2019; Volpajola, 2013).

Therefore, to save the chestnut trees in these abandoned castagnetu, and consequently to safeguard the future of this chestnut agroforestry system, a large-scale restoration of abandoned castagnetu is needed, which is what this thesis aimed to investigate.

The main research question of this Master Thesis was:

How can a large-scale restoration of Corsica's abandoned castagnetu be achieved?

According to Horlings *et al.* (2020), transitions and transformations of (agricultural) systems (here the restoration of abandoned castagnetu) are always influenced by processes belonging to three different pillars (social-cultural, ecological and political-economic) and to gain a profound understanding of how all these different processes impact the restoration of Corsica's abandoned castagnetu, the sustainable place-shaping conceptual framework **(Fig. 2)** developed by Horlings *et al.* (2020) was used to organise this thesis.

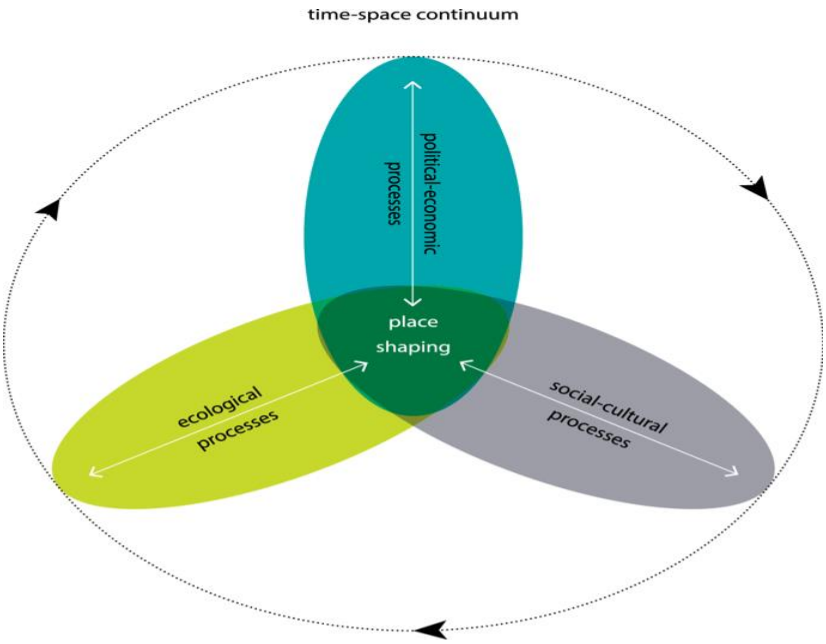

Figure 2. The sustainable place-shaping contextual framework developed by Horlings et al. (2020).

Following the structure of this framework, three research questions each belonging to one of the three pillars (ecological, social-cultural, political-economic) of the framework were used:

Research question 1:
how do ecological problems contribute to the low productivity of abandoned chestnut trees and what is needed to solve these ecological problems?

Numerous ecological problems (briefly mentioned above) drastically reduce the productivity of the chestnut trees and endanger the future survival and production of many abandoned chestnut trees. Therefore, the first research question aimed to investigate which ecological problems influence the restoration, through which mechanisms, and what can be done to solve these problems.

Research question 2:
how do social-cultural factors complicate the restoration process and what can be done about it to facilitate the restoration?

This second research question researched the different social-cultural processes impacting the restoration. Several social-cultural processes, most importantly Corsica's special land registration system which complicates the access to land (abandoned castagnetu) and therefore discourages young Corsicans from becoming chestnut farmer, influence the large-scale restoration of abandoned castagnetu (Rey-Lefebvre, 2017).

Research question 3:
how do political-economic factors discourage Corsicans from getting involved in the restoration process and what solutions could be implemented to counteract this?

The third research question investigated the economic and political challenges interfering with a large-scale restoration.
The current grim economic situation (low production, see **Fig. 1,** lots of ecological problems threatening the future, shortly introduced above) faced by chestnut farmers explains why the

number of chestnut farmers has only slightly increased in the last eight years, from 77 in 2010 to 84 in 2018, mostly because some family enterprises were split up into independent farms (DRAAF Corse, 2015, 2019). These economic aspects are therefore relevant because they prevent many Corsicans from becoming chestnut farmer and, therefore, hinder a large-scale restoration.

From a political point of view, this question aimed to investigate the willingness among different stakeholders to allocate financial resources to the restoration of the abandoned castagnetu.

2. Materials and Methods

2.1 Organisation of the research

A case study approach was used to study the Corsican situation. The objective was to gain a profound understanding of all local, place-bound factors that influence the restoration process. In total, three different research methods were used (desk research, literature review, semi-structured interviews). These methods can be split into two parts that represent the two phases of this research:

- Phase I of the research aimed to prepare the semi-structured interviews (phase II) by exploring the different processes and factors relevant to each research question. Desk research and a literature review were chosen to achieve this objective and are described below.
- Phase II of the research consisted of semi-structured interviews with local Corsican actors (which will be introduced later in detail). The purpose of these interviews was to learn about the local, place-bound processes (ecological, social-cultural and political-economic) impacting the restoration in Corsica which cannot be uncovered by a literature review and desk research alone. All three research questioned were investigated during the interviews and the details are provided below.

Phase I of the research: desk research and review of scientific literature
Desk research, consisting of the consultation of newspaper articles, government documents and other multi-media documents, was conducted to explore the processes and factors connected to the three research questions. Its primary objective was to gain a global understanding of the Corsican context, allowing the author to prepare the semi-structured interviews in detail. Its second objective was to complement the findings from the interviews to help answer the research questions.

Secondly, because of the technical nature of the first research question and the abundance of available scientific literature concerning the ecological problems investigated by this question, a literature review was conducted to complement the qualitative data obtained through the semi-structured interviews. Relevant publications about the ecological problems (presented in the first section of the results) in the English, French and Dutch scientific literature were consulted.

From the desk research and the literature review, it emerged that the homogeneity of the castagnetu (a monoculture of chestnut trees) is a primary cause of the challenging economic and ecological situation faced by current and future chestnut farmers. A potential solution could be the diversification of castagnetu. Two promising diversification strategies (growing shiitake mushrooms and planting hazelnuts in the castagnetu), based on the author’s experience and academic work concerning the chestnut agroforestry system, were investigated (ecological and economic performance) in detail through desk research before conducting the interviews. A short document that summarises these findings was created (**Appendix B)** and these diversifications were discussed with the chestnut farmers in phase II of the research: the semi-structured interviews.

Phase II: semi-structured interviews

Semi-structured interviews were conducted with a total of sixteen participants. Seven of them were professional chestnut farmers and the other nine had different professions. The professional chestnut farmers were particularly knowledgeable about the ecological and economic processes and factors impacting a large-scale restoration of castagnetu. However, because a large-scale restoration requires changes in the ecological, political-economic and social-cultural processes, expertise from all three categories is required and therefore, other actors which will be introduced shortly, were interviewed as well.

The professional Corsican chestnut farmers were selected through purposive sampling (Bernard, 2017) informed by suggestions from Ms Patricia Soullard, the Corsican expert of the chestnut agroforestry system working for the *"Chambre d'Agriculture de Haute-Corse*" (hereafter referred to as "*Chambre*"). Chestnut farmers were chosen in particular because of their knowledge about the ecological challenges faced by the chestnut trees and three selection criteria were used.

The first selection criterion was that the farmer should be a professional chestnut farmer registered by the "*Groupement Régional de Producteurs et Transformateurs de Châtaignes et Marrons de Corse*" (hereafter referred to as "*Groupement*"), which is Corsica's local chestnut producers group (AOCfarinedechâtaigne, 2019a).

The second selection criterion was to include farmers from different generations.

Lastly, farmers from different regions were selected to investigate regional differences or similarities (**Table 2).**

All Corsican professional chestnut farmers (84 in 2018) are AOC-certified (DRAAF Corse, 2019b). AOC (Appellation d'Origine Contrôlée meaning "controlled designation of origin") is a French certification granted to different agricultural products to protect their geographical origin. Therefore, only AOC-certified farmers could be interviewed.

Table 2. Overview of the seven professional chestnut farmers that were interviewed.

Farmer (pseudonyms)	Function(s)	Scale of orchard	Age	Region of farm
1 Anne (and son Vincent)	Professional chestnut farmer who also engage in other agricultural activities such as keeping bees and growing fruits.	Small (several ha)	Fifties	Castagniccia
2 Olivier	Professional chestnut farmer and expert chestnut pruner.	Large (>30 ha)	Thirties	Tavignano
3 Fabien	Professional chestnut farmer who also raises pigs.	Large (>30 ha)	Sixties	Castagniccia
4 Francis	Professional chestnut farmer.	Large (>30 ha)	Thirties	Castagniccia
5 Gabriel	Professional chestnut farmer who also raises sheep in his castagnetu and professionally works for Corsica's chestnut sector.	Medium (10-15 ha)	Fifties	Niolo
6 Francois	Retired professional chestnut farmer and mill expert.	Large (> 30 ha)	Seventies	Castagniccia
7 Antoine	Professional chestnut farmer who also has honeybees, and is the mayor of a rural Corsican village.	Medium (10-15 ha)	Fifties	Castagniccia

Concerning the other nine participants who were not professional chestnut farmer, a diversity of participants was deliberately selected. Some of the participants were selected through purposive sampling informed again by suggestions from Ms Soullard, others were directly selected based on their unique background or profession and knowledge about relevant subjects of the questionnaire. An example for such a case was Thibault who is the founder of a unique subtropical food forest in Corsica that, based on decades of experience, is considered the Corsican expert about agricultural diversification (**Appendix C).** Another example of direct selection based on someone's unique knowledge was the selection of two Corsican experts of Corsica's chestnut agroforestry system, Léa and Camille, who professionally work for the chestnut sector and are considered by most chestnut farmers to be the most knowledgeable people about this topic. A complete overview of these nine other participants and their backgrounds can be found in **Appendix C.**

2.2 Data collection and analysis

Phase I of this research (desk research, literature review) was in large used to prepare phase II (the semi-structured interviews). Topics and relevant questions to be discussed during the semi-structured interviews were chosen and a questionnaire (**Appendix D)** was created. This questionnaire used during the semi-structured interviews consisted of three parts that match the structure of this research: ecological, social-cultural and political-economic factors influencing the restoration.

Due to Covid-19, eleven interviews were conducted by telephone and five were conducted in person. Before starting the interview, participants were asked to sign a consent form (**Appendix E)** (in the case of in person interviews) or (in the case of telephone interviews) were orally presented the content of the consent form and asked for their approval.
After a brief introduction of the aim of the research, the participants were encouraged to share all the information they thought could be relevant during the interview, even if the questionnaire did not address these subjects.

Not all participants were asked the same questions. Due to the deliberate inclusion of participants with different societal backgrounds, the participants were asked questions specified to the specific participant's knowledge and background.
However, most (groups of) participants were, despite a focus on topics related to his/her expertise, knowledgeable about a wide range of topics and provided answers to many different topics. This was helpful to better understand the different (sometimes conflicting) perspectives (from different actors) on how to revitalise Corsica's abandoned castagnetu.

Interviews were conducted in French (twelve), English (two) and Dutch (two) and took on average 73 minutes. All interviews were recorded and stored online on Google Drive, which only the author and the supervisors could access to protect the privacy of the participants. Pseudonyms are used in this document to protect the privacy of the participants.

To analyse the interviews, deductive coding was used. Before the first interview was conducted, an Excel sheet (**Appendix F)** was created based on the prepared questionnaire (**Appendix D).** All the topics that were to be covered for each research question were listed and the answers belonging to these topics were entered in this Excel sheet. The responses from the different actors were compared, and the multi-actor perspective framework developed by Avelino and Wittmayer (2016) (**Fig. 3** in results**)** was used to understand which and how actors influence the restoration of the abandoned castagnetu. This framework is used for qualitative research to categorise all relevant actors (state, market, community, Third Sector) involved in a process (here the restoration of abandoned castagnetu) which helps understand the relationships and power relations between actors (Avelino and Wittmayer, 2016). Furthermore, after adding the relevant actors to the framework, conflicts (or conflicting visions) between actors were indicated in the framework to investigate which different roads to a large-scale restoration could be followed and if (and if so, how) different visions could interfere with each other, and therefore interfere with the process of restoration.

3. Results

The results are grouped per research question. For each research question, the most important processes or problems that influence the restoration of abandoned castagnetu are presented. For each topic, a problem description and background is provided firstly, followed by the solutions to the problem and, if relevant, expected future development.
After presenting the results belonging to the three research questions, the interactions between different actors and how these interactions influence the restoration process are presented, using the multi-actor perspective framework. The quotes that are used were translated in English from the French and Dutch original statements.

I Ecological challenges: a serious threat to the future survival of abandoned chestnut trees

From the most important ecological issues (the chestnut gall wasp, chestnut blight and ink disease, climate change and feral animals) that impact the restoration of Corsica's abandoned castagnetu, the chestnut gall wasp has had the most substantial and most acute impact on the productivity of the chestnut trees in the last decade and is responsible for a drastically reduced productivity (**Fig. 1)**. Besides the chestnut gall wasp, chestnut blight is a harmful fungal disease that has been spread by the chestnut gall wasp in recent years and that seriously impact the abandoned castagnetu. Chestnut ink disease, climate change and feral animals are other ecological problems that impact the abandoned chestnut trees. Because their impact on the abandoned castagnetu is inferior to that caused by the chestnut gall wasp and chestnut blight, only a brief overview will be given here. Further detailed information can be found in the appurtenant appendixes indicated in the text below.

3.1 Oriental chestnut gall wasp

3.1.1 Background and problem description

The chestnut gall wasp *(Dyocosmus kuriphilus)* is a hymenopteran insect that originates from China (Otake, 1980). Its hosts include the Chinese, Japanese, American and European chestnut as well as most of its hybrids (European and Mediterranean Plant Protection Organization, 2005). The chestnut gall wasp reproduces via parthenogenesis (European and Mediterranean Plant Protection Organization, 2005).
Its life cycle depends on chestnut trees; larvae reside in the flower and leaf buds of the last year's growth. They transform into adults in spring which induces the formation of gall tissue. In early summer, the adults emerge from the galls and lay their eggs in the new buds (for next year). After oviposition, the adults (females only) die quickly. In these buds, the larvae hatch but remain relatively inactive until spring next year. Next year's spring, the larvae transform into adults, and the cycle starts again (Cho and Lee, 1963).

This process is harmful to the chestnut tree because the induced galls make the proper development of flowers and leaves impossible (Avtzis *et al.*, 2019), resulting in a sharply reduced abundance of flowers, but also in a reduced leaf size which impairs the photosynthetic capacity of the trees (Bucchini, 2013). It is considered the most important pest for chestnuts in the world (Aebi *et al.*, 2006).
Its first appearance in Europe was documented in 2002 in Italy (Brussino *et al.*, 2002; European and Mediterranean Plant Protection Organization, 2005) and it was likely brought to Europe with the import of wood two years earlier than its official documentation (Quacchia *et al.*, 2013). Since its first appearance, it has rapidly spread over the rest of Europe, arriving in France and Slovenia in 2005 (Aebi *et al.*, 2006) and subsequent years in many other European countries (Avtzis *et al.*, 2019). Its first observation in Corsica was made in 2010, and afterwards, it spread rapidly over the rest of the island (AOCfarinedechâtaignecorse, 2018).

It has strongly affected Corsica's chestnut production; virtually all Corsican orchards had yield losses between 50 and 100% in the subsequent years after the arrival (Bucchini, 2013; DRAAF Corse, 2018). The accompanying financial loss in Corsica is estimated to be around €3 350 ha^{-1} $year^{-1}$ (Bucchini, 2013) so for a farmer owning twenty ha of castagnetu, the five-year losses could add up to 335 000 euro.

Furthermore, the arrival of the chestnut gall wasp in 2010 has worsened the blight disease problems in Corsica because the chestnut gall wasp serves as a vector for the dispersal of the disease; every time it lays its eggs in a bud of a chestnut tree, it can also distribute the blight disease (AOCfarinedechâtaignecorse, 2019b; DRAAF Corse, 2019a; Meyer *et al.,* 2015; Prospero and Forster, 2011; Rigling *et al.*, 2014).

3.1.2 Solutions

Financial aid program

To compensate for the strongly reduced production of chestnuts in most castagnetu in the years after the arrival of the chestnut gall wasp, a financial aid program was launched in 2013. The threshold was set on €2 000 ha^{-1} $year^{-1}$, for five years and maximally ten ha $farmer^{-1}$ (Bucchini, 2013). This does not completely compensate for the financial losses (estimated to be around €3 350 ha^{-1} $year^{-1}$ (Bucchini, 2013) but has been effective enough to ensure the continuation of virtually all chestnut farmers (DRAAF Corse, 2015, 2019). Furthermore, this solution does not address the root cause and does not contribute to solving the problem, but has been important to ensure the chestnut farmers' survival.

Classical biological control based on *Torymus sinensis*

Since the arrival of the chestnut gall wasp, a large-scale biological control program has been launched (AOCfarinedechâtaignecorse, 2018) which is detailed in **Appendix G**. It is based on the mass release of *Torymus sinensis*, an almost exclusively monophagous *Torymidae* parasitoid that is native in China where it effectively controls the populations of the chestnut gall wasp. *T. sinensis* lays its eggs in the same buds that the chestnut gall wasp uses to lay its eggs. After hatching, the larvae of *T. sinensis* eat the larvae of the chestnut gall wasp and thereby reduce the next year's population of the chestnut gall wasp (Cho and Lee, 1963).

In Japan, Italy and continental France, where the biological control using *T. sinensis* started years earlier than in Corsica, the results look promising (**Appendix G).** However, it takes time: around seven to nine years before the damage caused by the chestnut gall wasp starts to seriously decline (Borowiec *et al.*, 2018; Ferracini *et al.*, 2019). In Corsica, *T. sinensis* was released for the first time in 2011 (Groupement Regional des Producteurs et Transformateurs de Chataignes et Marrons de Corse, 2017; Volpajola, 2013). In line with the observations in other regions where *T. sinensis* was released, all interviewed farmers had started to see the first signs of improvements since approximately one or two years ago (so seven to eight years after the first *T. sinensis* releases - higher yields, healthier-looking trees, see example in **Appendix H**).

However, the degree of improvement strongly depended on the location of the orchards. For example, for Antoine, a chestnut farmer in the north of Castagniccia, 2019 was a relatively good year with a production that was more than 50% of the production before the arrival of the chestnut gall wasp (after several years without any production), while the production of Olivier's trees, a chestnut farmer in the south of Castagniccia, was still severely reduced in 2019. He expected it would take several more years before *T. sinensis* would become truly effective. The explanation for this discrepancy is the fact that the first releases of *T. sinensis* (the experimental ones) were performed in the northern part of Castagniccia close to Bastia so this part of Corsica is several years ahead of other regions.

Selection of tolerant varieties

From >60 screened *Castanea sativa* (European chestnut) cultivars, only two varieties have been found to have excellent resistance against the chestnut gall wasp: *Savoye* (from the French Pyrenees) and *Pugnenga* (from the Piedmont region in Italy) (Sartor *et al.*, 2015).

Besides European chestnut cultivars, some Japanese-European hybrids are also resistant: *Bouche de Bétizac, Marlhac, Maridonne* and *Vignols* (Sartor *et al.*, 2015) but Camille and Léa, two Corsican agricultural experts working for the chestnut sector, emphasised the fact that the Corsican sector has deliberately chosen to only work with endemic Corsican varieties. The cultural attachment to Corsica's endemic varieties, which are considered Corsican heritage, was the decisive factor. Therefore, none of the presented resistant varieties are suited for the Corsican context.

There is one endemic variety called "*Campanese*" which has a certain degree of resistance to the chestnut gall wasp and this variety allowed some farmers, such as Fabien, an experienced large-scale farmer in Castagniccia, to maintain a relatively high production after the arrival of the chestnut gall wasp.

3.1.3 Future

Even though the chestnut gall wasp has had a deleterious impact on the chestnut production in Corsica, (many farmers indicated that in the first years after the chestnut gall wasp's arrival, the trees no longer provided substantial shade due to the reduced leaf size and abundance caused by the chestnut gall wasp, and many said that their production had plummeted to (almost) nothing for a couple of years), most participants were optimistic about the future development of the situation. They were convinced that the biological control with *T. sinensis* would be fruitful.

3.2 Chestnut blight

3.2.1 Background and problem description

Chestnut blight is a fungal disease that is caused by *Endothia parasitica* (asexual form) and *Chryponectria parasitica* (sexual form). Here, for convenience, the name *E. parasitica* (or chestnut blight) is used to describe the problems and solutions.
The disease was introduced in Europe at the beginning of the 20th century from and was first observed in Italy in 1938, from where it spread over most other European countries China (Milgroom *et al.*, 1992). At the beginning of the century, the disease was already present in most French regions where chestnuts were commercially grown (Robin and Heiniger, 2001).

E. parasitica spores can infect the tree's stem and branches via small openings (caused by damage) in the bark. The fungus consequently induces a toxically low pH in the cambium cells of the trees; this kills the cambium cells and stops the xylem and phloem transport (Metcalf, 1913). Usually, this only kills the part of mature trees above the point of infection (Milgroom *et al.*, 1992). Only seedlings will frequently die upon infection (Rigling *et al.*, 2014).

The fungus can disperse by the production of spores, both asexual (conidia) and sexual (ascospores) spores (Rigling *et al.*, 2014). During humid and warm weather, conidia are produced and released which are mainly transported by rainwater (short distance) and animals (long(er) distance) such as insects, snails, birds and cattle (Rigling *et al.*, 2014; Scharf and DePalma, 1981). These animals can collect the spores on their skin, fur, exoskeleton and feathers if they come into contact with the fungus on the tree (Russin *et al.*, 1984). The ascospores are mainly transported by wind and reach further places than the conidia (Rigling *et al.*, 2014).

In Italy, around 1951, the first spontaneous healing of diseased chestnut trees was observed (Rigling *et al.*, 2014). A new healthy bark formed underneath the infection point and the fungus seemed unable to penetrate this newly-formed barrier that prevents the infection of the tree's cambium cells (Robin *et al.*, 2010).
It appeared to be not the tree which had developed a resistance to the fungus, but the weakening of the original fungus that made it lose its virulence (Rigling *et al.*, 2014; Robin *et al.*, 2010). It turned out that a dsRNA virus called *Cryphonectria hypovirus 1* (CHV1) had infected *E. parasitica*, making the fungus less detrimental and giving the chestnut the chance to recover. This virus-infected variant of the fungus is called a *"hypovirulent strain".*
The hypovirulent strain was accidentally introduced to Europe (likely from the import of Japanese or Chinese chestnuts (Heiniger and Rigling, 1994) and in a few decades, it had spread over most of Italy, resulting in the healing of many diseased trees (Heiniger and Rigling, 1994).
Without human help, the hypovirulence spread throughout Europe in several decades.

At the turn of the century, chestnut blight was omnipresent in most European chestnut-growing countries, but its impact on the productivity of the trees depended on the presence of the hypovirulence in the region (Robin and Heiniger, 2001). In regions where the hypovirus was well-represented, the severity of the blight was low. In regions without significant hypovirus presence, the impact on chestnut productivity is serious, and actions need to be taken to restore it (Robin and Heiniger, 2001).

3.2.2 Solutions

A detailed overview of the different methods to control the chestnut blight disease is provided in **Appendix I.** In short; these are the different methods that can be used:

<u>Biological control using hypovirulent strains</u>

Diseased chestnut trees can be inoculated with CHV1 virus-infected strains of the blight fungus. The virus is transmitted by the hypovirulent blight inoculant to the virulent not-infected blight strain when the two strains merge and the tree can heal (Robin *et al.*, 2010). This method is highly effective and most farmers were aware of this effectivity.

However, several farmers critiqued the biological control method for its time and labour consumption; to treat all the canker spots on the often hundreds of trees that belong to a farmer, the farmer must climb into the trees to reach the canker spots to inoculate them. This is a labour-intensive and time-consuming process, especially in combination with the challenging topography of most orchards.

Biological control in Corsica by infecting existing cankers with the CHV1 virus seems to be implemented less frequently compared to other French regions (Robin *et al.*, 2000), indicated by the relatively low treatment of castagnetu in 2000; around 20% of the tested castagnetu was treated with biological control, while this percentage was 38 and 29% in Ardèche and Dordogne, respectively (Robin *et al.*, 2000).

However, Léa and Camille, the two Corsican chestnut experts working for the sector, confirmed that after 2000, the number of performed treatments was increased. Therefore, the actual Corsican situation could be more like Ardèche and Dordogne, but unfortunately, more recent literature about the current treatment numbers are not available.

Sanitary practices to limit the spread

Fencing castagnetu prevents the spread of the disease as feral animals, which are abundant in Corsica (discussed below), can function as vectors (which is discussed in detail in **Appendix J)** (Rigling *et al.*, 2014; Scharf and DePalma, 1981). Furthermore, the use of dead chestnut wood (see **Appendix I)** can either spread the blight through the orchard or speed up the development of hypovirulence (Meyer *et al.*, 2019; Prospero *et al.*, 2006).

Blight disease was regularly called *"the disease of abandonment"* by participants as they suggested that careful pruning of infected branches can control the disease. In Corsica though, not all chestnut farmers prune their trees themselves. As pruning is a dangerous job, some farmers hire specialised pruning companies to do the work. Care must be taken as some pruning companies do not prune the trees lightly but very vigorously. According to Gabriel, one of Corsica's most experienced chestnut-pruning farmers, this vigorous pruning is detrimental to the chestnut's health: being a fruit tree, it only tolerates light pruning.

Cultivar choice

Several Euro-Asian hybrids, such as Bouche de Bétizac, show increased resistance to the blight (Hennion, 2009; L'institut de l'agriculture et de l'alimentation biologiques, 2001). However, as mentioned earlier, the Corsican chestnut sector has deliberately chosen to only work with endemic chestnuts, but no endemic resistant variety has ever been observed in Corsica.

3.2.3 Future

Concerning the future of the disease, it turns out that mainly the abandoned chestnut trees are in grave danger while the trees in managed castagnetu can be protected by careful pruning and biological control. As noted earlier, blight is spread by the chestnut gall wasp, and this explains the recent increased incidence of blight in Corsica (AOCfarinedechâtaignecorse, 2019b; DRAAF Corse, 2018; Meyer *et al.*, 2015; Prospero and Forster, 2011; Rigling *et al.*, 2014). Even though the damage caused by the chestnut gall wasp is currently getting less, the massive spread of the fungus across the abandoned castagnetu in the last decade seriously endangers the future of many chestnut trees.

3.3 Chestnut ink disease, feral animals and climate change

Besides the oriental chestnut gall wasp and chestnut blight, three other ecological problems impact the restoration of abandoned castagnetu:

- Chestnut ink disease
- Feral animals
- Climate change

These problems are considered to be of less importance than the chestnut gall wasp and chestnut blight. Therefore, they are only briefly described here. Detailed information can be found in the appendixes mentioned below.

Firstly, chestnut ink disease is another fungal disease (caused by *Phytophthora* oomycetes that affect the chestnut's roots) that is more devastating than blight but less widespread. However, in recent decades an increased incidence has been observed, and several participants fear that ink disease will become the most problematic ecological issue in the near future, mostly because there is a lack of understanding of the possibilities to control the disease among the farmers. The role of free-roaming pigs (described hereafter and in **Appendix J**) was often mentioned as one of the most important reasons for this increased incidence.
In **Appendix K,** the disease, as well as the possibilities to control it, are described in detail.

Secondly, thousands of feral animals, mostly pigs, cows and goats, roam around Corsica's countryside and negatively impact the abandoned castagnetu because they disturb the soil of the castagnetu, they accelerate the spread of ink disease and blight, and they reduce the regeneration of the orchard by eating chestnut seedlings (Rigling *et al.*, 2014; Scharf and DePalma, 1981). Solutions to this problem are fencing and population control (hunting). **Appendix J** provides a detailed description of the problems caused by the feral animals and the solutions.

Thirdly, climate change seriously threatens the future of the abandoned chestnut trees in Corsica. Droughts have been occurring more frequently in the last decades which is problematic because August rain is vital to produce (big) chestnuts.
To adapt to climate change, green manures which should improve the soil structure of castagnetu are currently tested. Moreover, the selection of drought-resistant varieties is investigated. **Appendix L** provides a detailed overview of the problem and its solutions.

II Social-cultural processes impacting the restoration

The second part of this thesis addresses the three most important social-cultural challenges that influence the restoration of abandoned castagnetu: access to land, the social status of (chestnut) farmers, and the bad social infrastructure of the Corsican countryside.

3.4 Access to land

3.4.1 Background and problem description

To give farmers the opportunity to restore abandoned castagnetu, they must be able to access the abandoned castagnetu. This is quite complicated in Corsica and two factors explain this.

Firstly, Corsicans were until recently exonerated from filing a declaration of inheritance of property (land or buildings), which is mandatory in most European countries (Rey-Lefebvre, 2017). Consequently, Corsicans were exempted from paying inheritance taxes, preventing the French Land Registration system ("*Cadastre*") from being up to date about property boundaries and ownership in Corsica. This exoneration started in 1801, and in the following two centuries, the land was inherited from generation to generation without registering who was the owner and where were the borders of the property. Consequently, properties (including abandoned castagnetu) have many different owners, while some of them do not even know they are the owner. Moreover, because owners are not registered (and therefore, it is not clear who are the owners), it is challenging to sell or to rent an abandoned castagnetu.

Secondly, Corsicans are fully exonerated from paying property taxes if the land is used agriculturally or forested and without construction (Capital, 2016; Gouvernement francais, 2014). This exoneration further reduces the will among the owners (if they can be identified) to sell the castagnetu.

Considering that almost all abandoned castagnetu, especially in the microregion of Castagniccia, are privately owned (Jan and Luitaud, 2017 - though there is a lot of joint-ownership), aspiring chestnut farmers can hardly start their farm as they cannot identify all the owners, or convince all the owners to sell or rent the abandoned castagnetu. The example given by Gabriel is symbolic for this challenge. Even though he is a respected well-known chestnut farmer, it took him almost 30 years to convince the owners of an abandoned castagnetu adjacent to his managed castagnetu to sell it.

3.4.2 Solutions

Associations Foncières Pastorales

To solve this impasse, so-called *"Associations Foncières Pastorales"* (Pastoral Land Associations) were founded several decades ago. People working for associations aim to find out who are the owners of a particular terrain by talking to village elders and by consulting municipal registers. It is a lengthy procedure, and even if all the owners of the land can be identified, some of the owners can refuse to sell the land, even though they do not use it.

Communalisation of abandoned castagnetu and facilitated sales

Another solution could be the communalisation of abandoned castagnetu to make them available to new chestnut farmers. Some of the participants such as Benjamin and Jean-Marc, two young Corsican farmers, suggested that the municipality should be given the legal power to communalise the land if owners do not manage their castagnetu. Such legal power would be both a way to make more land available for new farmers and an incentive for owners to manage the castagnetu.
This idea has not yet been formalised, but a 2017 law proposal that aimed to tackle the same issue (the transmission of the land) was accepted by the French Parliament. The senators decided that to sell property, a majority of just two-thirds of the owners is required while on mainland France, unanimity among the owners is required (Rey-Lefebvre, 2017).

Involvement of non-farming private castagnetu owners to by-pass the problem of land transmission

Another solution, which was promoted by several Corsican scholars such as Bernard in recent years, seeks to by-pass this problem of making land available to new farmers and aims to restore the abandoned orchards without needing professional chestnut farmers to take over the orchards.
As mentioned earlier, most abandoned castagnetu are privately owned (be it by many owners) and currently, private castagnetu owners who are no professional chestnut farmers are not granted any financial resources to restore their properties.
This is problematic because the costs related to the restoration of abandoned castagnetu are high: the costs to restore one ha (clearing of the understory, pruning, grafting, fencing – the entire process is detailed in **Appendix M**) can easily surpass €10 000 (Collectivité Territoriale de Corse and Office du Développement Agricole et Rural de Corse, 2014). Therefore, non-professional farmers who own abandoned castagnetu do not have the means to restore their properties.

The proposition of several Corsican scholars is to make financial resources available to the castagnetu owners (no professional chestnut farmers) who want to manage the chestnut trees in the orchard from the moment it is restored onwards (Michon *et al.,* 2011). It is argued that the initial restoration costs are the bottleneck that prevents a large-scale restoration of these privately-owned abandoned castagnetu and that by overcoming this initial hurdle, these non-farming landowners can be of vital importance to the large-scale restoration of abandoned castagnetu.

However, the chestnut sector is slightly sceptical about the success rate of this idea, according to Léa and Camille, the two professionals of the chestnut sector who participated in this study. They argue that if financial resources would be made available, it is questionable if they will reach the right persons and if these resources will be used efficiently. An essential condition to roll out such a plan would be to introduce a strict control process that would enable to assess how the money is used. If such a reliable control could be realised, the chestnut sector would be supportive of this idea to involve other actors to the restoration of what Léa called:

"this Corsican heritage that belongs to all Corsicans, not only the professional chestnut growers".

3.5 Social status of chestnut farmers and bad social infrastructure chestnut-growing regions

3.5.1 Background and problems situation

The young Corsican generation prefers a different lifestyle than the lifestyle of a chestnut farmer, according to all participants of this study. Most young Corsicans prefer to live in the cities, to have a job that does not require high physical activity and that relatively easily generates an income. Chestnut farmers are considered by most young Corsicans as having a poor social status; in France and Corsica, according to Bernard and Gabriel, choosing a career as a farmer is something that is looked down upon. A Corsican saying that was popular in former times mentioned by Bernard was:

"I saw two men and a shepherd",

showing the disdain for the farming profession. These days, the situation seems to improve due to a more global ecological awareness of the need of proper land stewardship. Still, according to Gabriel:

"In France, becoming a farmer is regarded as a foolish choice".

Beside the low societal status of chestnut farmers, another key social-cultural problem is the bad social infrastructure of chestnut-growing regions.
Several participants mentioned that as a parent, it would be required to drive two times a day to the nearest city to drop off and to pick up the children. It can easily take an hour per drive due to the mountainous roads. Furthermore, bars, restaurants, sport clubs and other social facilities are rare in these rural regions. Even the nearest shop can be a one hour drive.

Together, these two social-cultural problems strongly reduce the will and interest among young Corsicans to become chestnut farmer and therefore, endanger the large-scale restoration of abandoned castagnetu.

3.5.2 Solutions

Making the young generation reconsider the chestnut farmer's lifestyle

Several participants suggested that the mind-set of the youth should be changed. Charles summarised elegantly why this is required:

"Youngsters do not want to give up their conveniences and possessions that are available in the cities, but it is not possible to live mainstream in these rural regions".

To inspire the young generation, the *Groupement* organises workshops at schools. However, it is questionable how much impact this would have on the children's mind-set.

Furthermore, several participants such as Antoine believed that the strict French lockdown due to Covid-19 would trigger a change of the mind-set among the young Corsicans that were confined for weeks in their homes in the cities. Because 37.2% of Corsica's inhabitants has a secondary residence (most often in a village in the countryside), many Corsicans moved to the countryside during the lockdown (Mattei, 2020). The people who were stuck in their city homes were hardly allowed to go outside for weeks while the people in the countryside could spend as much time as they wanted on their farm and in their gardens. It was hoped that the young generation would realise the benefits of living and working in the countryside and would embrace another lifestyle (in the countryside, such as chestnut farmer, vs in the cities).

Rural development

Rural development programs (by the European union or the French government) could make Corsica's countryside more attractive to young people. An example of such a rural development is the recent modernisation of many roads in Alesani valley, in Castagniccia. As observed by Charles, an expert of diversified agricultural systems, who lives in this valley, a lot of old roads have been modernised in the past years to improve the connectivity between the rural villages in this valley and the cities close to the sea.

Another aspect of rural development that could help attract more young people, would be to subsidise schools in the countryside which could prevent them from closing. Last year, Charles mentioned that not a single school was opened in the Orezza valley, which was the political and economic heart of the island for centuries and which supported population densities of up to 140 inhabitants km^{-2} (Michon, 2011). This symbolises the collapse of the chestnut civilisation and repels young families (of chestnut farmers) from living in the countryside.

III Economic-political processes impacting the restoration

The third research question considered the economic and political challenges that complicate a large-scale restoration. Poor economic prospects due to the high restoration costs and the lack of chestnut-related income for several years after the initial restoration are a root cause for the bad social status of chestnut farmers (discussed under 3.5), and therefore, are a major hurdle to overcome in order to realise a large-scale restoration.

3.6 Restoration costs

3.6.1 Background and problem description

The restoration of abandoned castagnetu (detailed in **Appendix M**) costs money. To restore one hectare, more than €10 000 is required (Collectivité Territoriale de Corse and Office du Développement Agricole et Rural de Corse, 2014). To become a professional chestnut farmer, according to Gabriel who is in the direction of the chestnut sector, a farmer needs at least 250 chestnut trees (equivalent to around five hectares). Therefore, if someone would like to become chestnut farmer, the restoration of five hectares of abandoned castagnetu would costs €50 000.

3.6.2 Solutions

<u>Subsidies</u>
The chestnut sector has launched several financial aid programs to cover the costs of the restoration (partly).
One well-known aid program is the so-called *“5.2-1 regulation*”. This regulation allows professional chestnut farmers to either plant new trees or restore abandoned castagnetu (to a specific upper limit of hectares) while getting reimbursed respectively 90 or 100% of the costs (Collectivité Territoriale de Corse and Office du Développement Agricole et Rural de Corse, 2014). It was initiated in 2016 in response to the crisis caused by the chestnut gall wasp. This regulation is directed to professional chestnut farmers so it is not of any use for aspiring chestnut farmers (who do not yet own land).

Another source of financial aid is the “*Office du Développement Agricole et Rural de la Corse”* (ODARC), which is a Corsican organisation that stimulates rural and agricultural development and plays a role in the financing of the restoration of abandoned castagnetu. Any Corsican that obtains the agricultural status can submit a plan for an agricultural project. If this plan is validated by ODARC, the new farmer receives a sum of money equivalent to several tens of thousands of euros depending on the activity, according to Francis, a young chestnut farmer who has recently begun. This money can then be used to finance the restoration.

3.7 Lack of income first years and poor economic prospects

3.7.1 Background and problem description

Another financial constraint is caused by the time that it takes to obtain a reasonable chestnut production after the restoration. After the restoration of a completely abandoned castagnetu, it is estimated by the participants that it takes five to ten years until a reasonable production of chestnuts is obtained. Therefore, the farmer does not have any significant income from the castagnetu for several years while the farmer still has to cover his/her living costs.

Furthermore, the poor economic prospects of the chestnut production due to the combination of ecological problems discussed in the first part of the results section discourage people from becoming chestnut farmer. Corsicans are aware of the history of the chestnut production and realise that the chestnut agroforestry system in its present form is a vulnerable agricultural system, as indicated by the collapse of the civilisation and the recent substantial fall in chestnut production due to the chestnut gall wasp. Therefore, a chestnut farmer is considered to have a low livelihood resilience and few Corsicans believe that becoming chestnut farmer is a smart choice from an economic point of view.

3.7.2 Solutions

<u>Subsidies</u>
Agricultural subsidies could help starting chestnut farmers survive the first years after the restoration when there is hardly any chestnut production. Like in the rest of Europe, the Common Agricultural Policy (CAP) subsidies could be an important source of income for starting chestnut farmers.
Currently though, most CAP subsidies are directed to cattle farmers in Corsica, who let their animals fend for themselves, thereby causing numerous ecological problems discussed earlier. According to Gabriel:

"My neighbours who are cattle farmers have an annual income of €100 000 while they abandon their cows, let them fend for themselves, resulting in the death of many of them".

He, together with others unveiled the, in their eyes, unfair distribution of Europe's agricultural financial resources. Gabriel argued that the chestnut sector receives very little financial resources compared to other sectors, mostly because it is such a small sector. According to Gabriel:

"*A change in the CAP is required to stop this cow comedy"*.

The CAP is currently being revised by Brussels for the next period and it is expected to favour more sustainable practices and to enable the young generation to become farmer. It is hoped that more money will be directed to more sustainable agricultural sectors, such as the chestnut sector which is, according to Vincent and Gabriel, one of the most environmentally friendly agricultural sectors. As stated by Vincent:

"*The chestnut sector was organic before the invention of the word. It is the most sustainable agricultural sector: the trees produce well for two to three centuries, provide fruits and wood, do not need a lot of water and do not require pesticides".*

Instead of European resources, Antoine, the mayor of a Corsican village, proposes to use regional or municipal resources available for rural development to provide new farmers with a basic income. His idea is to provide a new farmer with a basic income for the first years after the initial restoration of the castagnetu so he/she can continue the general management of the castagnetu. When the castagnetu starts to produce enough to finance the farmer's living costs, the basic income will be stopped.

Antoine argues that the costs associated with this idea will be compensated in the long run: the boost of economic activity, the prevention of a complete depopulation, and the protection of the village against wildfires when adjacent castagnetu are managed and will compensate the expended financial resources.
Concerning the protection against wildfires, which are a big threat in Corsica, chestnut farmers can, by clearing the understory of the castagnetu, achieve the same goals as professional fire fighters, which are heavily subsidised, while also achieving other objectives (boosting rural economy) not achieved by the firefighters. Therefore, some participants such as Antoine and Gabriel proposed to allocate a part of the budget currently used to pay fire fighters, to new chestnut farmers.

Diversification of activities

Diversification of activities would, by not putting all the eggs in one basket, enhance the resilience of farmer's livelihoods, and could be a solution to the poor economic prospects of chestnut farmers. Moreover, it could provide new chestnut farmers with an income from the first years onwards.

Diversification of activities was widely implemented by the current Corsican chestnut farmers. A clear separation between agricultural diversification and non-agricultural diversification could be made. Popular agricultural diversification methods were raising sheep or pigs in the castagnetu. Moreover, beekeeping and growing olives were two widely-implemented diversification strategies. Other, less common agricultural diversification methods implemented by some chestnut farmers were: growing hazelnuts, growing aromatic herbs (like curry herb), growing saffron, and growing fruit trees (mainly apples). Non-agricultural diversification strategies regularly implemented were mountain guide and the organisation of site visits to the farm. A list of all the different diversification options is provided in **Appendix N.**

System diversification

The most crucial argument in favour of diversified castagnetu is the increased spatial and genetic diversity that results in an enhanced resilience of the system as a whole to cope with new stressors such as diseases (Urruty *et al.*, 2016). Because Corsican castagnetu are monocultures of chestnut trees, the system is vulnerable because it stimulates the spread of (new) pathogens or pests. This has been clearly documented for chestnut ink disease: the disease can spread via root-root contact between neighbouring chestnut trees and the spread of the disease is therefore facilitated by homogeneous castagnetu rather than diversified castagnetu, containing other species (Martins *et al.,* 2007).

Therefore, diversification of the castagnetu could kill two birds with one stones; it could enhance the farmer's livelihood resilience (economically) by providing the farmer multiple sources of income, and it could enhance the castagnetu's resilience (ecologically) by making the system structurally more complex. Furthermore, it could generate an income quickly (if a diversification strategy that pays off after a few years is chosen).

Interestingly, hardly any system diversification (diversification of the castagnetu) was implemented by the professional chestnut farmers. The only real system diversification that was regularly implemented was raising sheep or pigs in the castagnetu. Diversification of the plant component of the system was almost non-existent which is a fundamental difference compared to other French chestnut-producing regions such as Ardèche where the cultivation of annual crops such as potatoes and wheat under the chestnut trees was commonly done in former times, as stated by Mr Pierron, a chestnut farmer in Ardèche, during an interview (F Pierron 2019, personal communication, 4 August). In Corsica however, this mixed land-use of the castagnetu has never taken place, so this culturally determined separate land-use explains the lack of vegetative diversity of Corsica's castagnetu that is observed these days, as stated by Ms Soullard, Corsica's chestnut expert working for the *Chambre* (P Soullard 2020, personal communication, 27 May).

The two diversification strategies (hazelnut and shiitake cultivation in existing castagnetu) that were investigated before conducting the interviews **(Appendix B)** were generally positively received by the chestnut farmers. All farmers were familiar with the hazelnut and appreciated its good economic prospects, while most farmers had never heard of shiitake mushrooms before. **Appendix N** provides detailed information about how these two diversification strategies were received, but in general it can be concluded that most participants showed a clear interest in the diversification of the castagnetu.

IV Interactions between actors that impact the restoration process

3.8 Different visions on how to achieve a large-scale restoration

The multi-actor perspective framework from Avelino and Wittmayer (2016) was used to understand which actors, from which societal sectors, influence the restoration processes. All relevant actors impacting the restoration were added to the framework. Furthermore, different visions between actors about how to achieve a large-scale restoration process were added to the framework and are labelled as "*conflicts*" here (**Fig**. **3**).

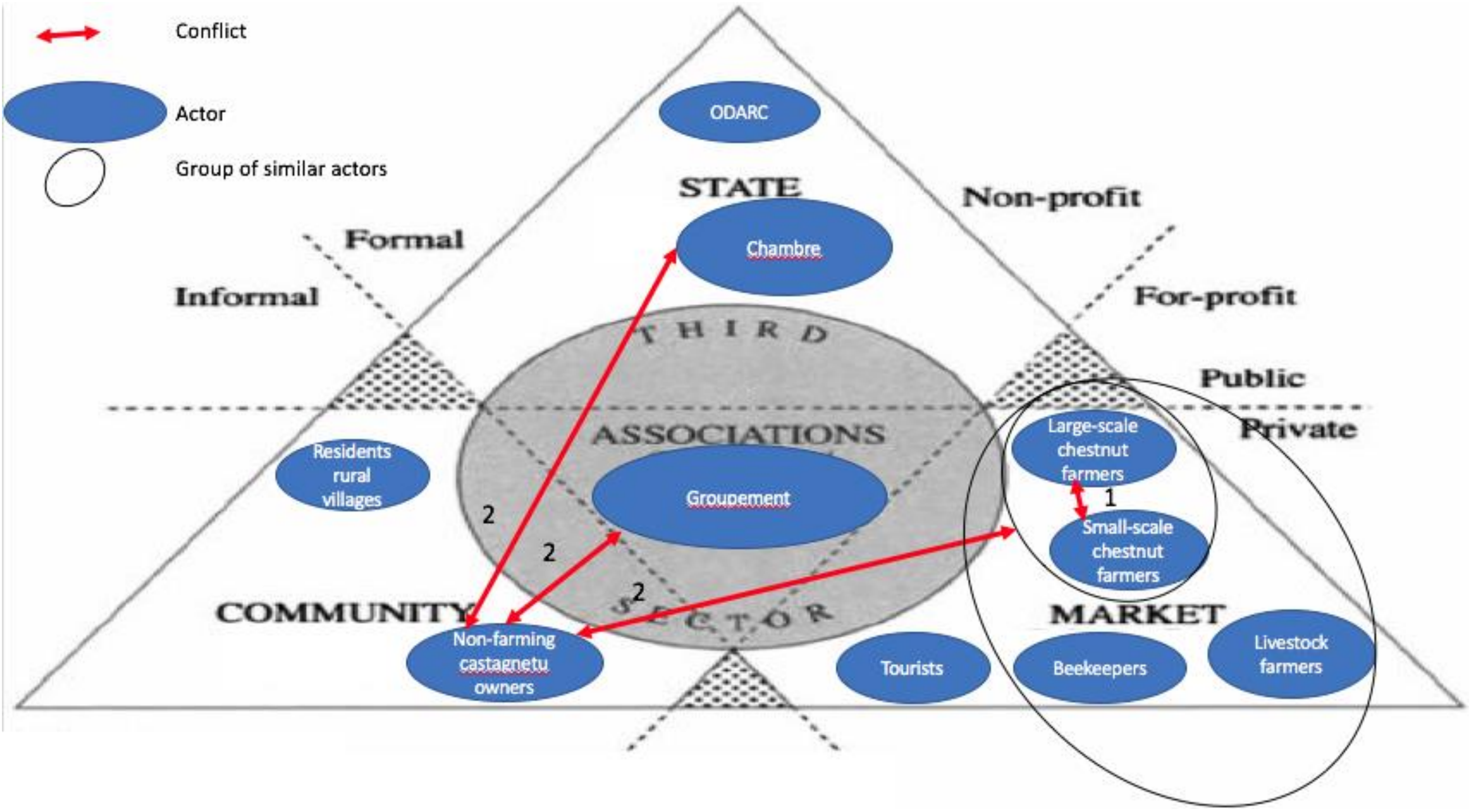

Figure 3. Multi-perspective framework developed by Avelino and Wittmayer (2016). Actors who influence the restoration process were added and conflicting visions between actors were indicated.

A large diversity of actors that impact the restoration process is present and several of them are connected to each other because they have different opinions about how to achieve a large-scale restoration. Two topics that result in different visions were observed and are presented here based on the number belonging to the topic in **Fig. 3.**

1: **should future chestnut farms be small-scale or large-scale?** Small-scale chestnut farmers such as Anna and Vincent believe that small farms (<10 ha of castagnetu) hold the key to a large-scale successful restoration of abandoned castagnetu. As put by Vincent:

"Small farms, small problems. Big farms, big problems".

He pointed out the need for careful treatment of the trees to allow them to overcome the ecological problems (careful pruning, for example). Therefore, his argumentation is that it is impossible for large-scale farmers (>30 ha of castagnetu) to take care of every unique chestnut tree (careful pruning, treatment of chestnut blight infections, general monitoring for water shortages).

On the other hand, large-scale farmers pointed out that scale-enlargement is required to make the profession of chestnut farmer economically viable in the current climate of low productivity. Having only several tens of trees can never be financially viable, so for professional chestnut farmers, large-scale farms are required. This vision is supported by the *Groupement* as Gabriel explained that the *Groupement* only considers someone as professional chestnut farmer (and, hence, it only accepts someone as a member) when the farmer owns a minimum of 250 chestnut trees.

2: **a focus on professional chestnut farmers only or the involvement of non-farming abandoned castagnetu owners as well in the process of restoration.**

As most abandoned castagnetu are still private (though joint-ownership) property, the involvement of non-farming castagnetu owners in the restoration process might be helpful for the restoration process in two ways:
A) There is no need for transmission of land to make a restoration happen.
B) Many Corsicans own several tens of chestnut trees which is not enough to be a professional chestnut farmer (according to the vision of the *Groupement).* However, if these castagnetu owners would be subsidised to restore their chestnut trees, like the professional farmers are subsidised, the involvement of them could contribute to a larger restoration than could be realised when only focussing on professional farmers.

However, the interviews showed a clear tension between the professional chestnut farmers (or the agricultural organisations connected to them: the *Groupemen*t and the *Chambre*) and the non-farming chestnut owners. In general, many professional chestnut farmers doubt the willingness among non-farming owners of abandoned castagnetu to manage their land after the restoration. For decades, the professional farmers argued, most abandoned castagnetu owners have consciously watched their chestnut trees die without doing anything to prevent it. Even if a farmer proposed to buy the castagnetu to save the trees, the owners most often turned down the offer. One of the most extreme cases was the example of Gabriel who had to wait around thirty years before the owner of the neighbouring abandoned castagnetu wanted to sell the land. By then, many chestnut trees had already succumbed because of the combination of ecological problems.
Because of this attitude, professional chestnut farmers and connected agricultural institutions were sceptical about the good intentions of abandoned castagnetu owners who would apply for subsidies to restore the orchard. Large-scale fraud was their major concern.

3.9 Collaboration between actors

The existence of different visions about how to achieve a large-scale restoration was complemented with the existence of a non-collaborative culture, thereby potentially complicating the large-scale restoration. Many participants indicated that cooperatives generally fail in Corsica; in Corsican traditional culture, the family is very important, and close collaboration and support between family members exists. However, unrelated Corsicans are quickly considered as strangers and distrusted. Therefore, cooperatives between unrelated Corsicans generally do not work out well.

4. Discussion

In the first part of the discussion, a connection between the ecological, social-cultural and political-economic processes and factors that impact the large-scale restoration of abandoned castagnetu will be made. The second part will discuss how the relationships between the different actors and the different visions concerning how to achieve a large-scale restoration restoration can interfere with the organisation of a large-scale restoration approach.

4.1 The chestnut needs his master, but the master has left

The metaphor *"opening a Pandora's box" (*filled with the chestnut trees' enemies) applies well to the Corsican case: the ecological problems (chestnut gall wasp, chestnut blight, ink disease, climate change and feral animals) together make the revitalisation of Corsica's chestnut agroforestry system a long-term project that requires actions on many different fronts.

This study highlights a fundamental weakness of agroforestry in a globally connected world: *the large impact of exotic diseases and pests*. The two fungal diseases (ink and chestnut blight) and the chestnut gall wasp are all exotic species, and our globalised world facilitates the spread of pathogens

and pests, hence posing a serious threat to agroforestry-based agriculture. Further recent evidence for this weakness of agroforestry systems to exotic pathogens and pests comes from another European agroforestry system, the olive groves in Italy.
Since 2013, millions of centuries-old olive trees in the southern regions of Italy have died due to the introduction of an exotic bacterial pathogen: *Xylella fastidiosa* subs. *pauca.* This strain was accidentally introduced in Italy from Costa Rica or Honduras via infected coffee plants and stops the transport of water, thereby killing the olive trees (Godefroid *et al*., 2019).

In the case of the chestnut agroforestry system, sufficient human involvement (in this case mostly by implementing biological control and general management such as pruning) can reasonably effectively control these exotic species, underlining the importance of the Corsican saying, "*the chestnut tree needs its master*".

The problem is that the master has left. But for a reason. The combination of ecological problems and grim economic prospects (because of the restoration-related costs and the economical vulnerability due to the dependence on a vulnerable agricultural system) is responsible for this lack of willingness among Corsicans to get involved in the restoration process.

Culturally, an interesting contrast can be observed. On the one hand, the chestnut is still an emblem for the Corsicans but on the other hand, hardly any Corsicans consider the profession of chestnut farmer as a serious career option. Becoming farmer is considered to be an unintelligent career choice, and because of the current problematic situation due to the ecological problems, a career as a chestnut farmer is discouraged by most parents.
Not only in Corsica, but in the whole of Europe, agriculture faces a serious problem with generational renewal (Eistrup *et al.,* 2019). The young generation prefers other career options and therefore, the future of Europe's agriculture (and therewith Corsica's), is uncertain.

In the case of Corsica's chestnut agroforestry system, even if there would be enough willingness among Corsicans to restore abandoned castagnetu, they would not be able to access the castagnetu because of the difficult access to land due to Corsica's former special land registration system.

To solve these social-cultural challenges, facilitating the access to land should be a priority and could be done by rural municipalities or by Pastoral Land Associations. Furthermore, the involvement of non-farming castagnetu owners by financially helping them to restore their abandoned orchard could accelerate the restoration process and by-pass the need to make orchards available to new farmers.

Concerning the grim economic prospects that contributes to the lack of willingness amongst Corsicans to become chestnut farmer, the combination of high investment costs required to restore the abandoned castagnetu and the lack of chestnut-related income for several years (estimated between five and ten) are major obstacles.

Solutions could be increased financial support for new farmers that not only cover the costs of the restoration, but that also provide a basic income during the first years after the restoration when the chestnuts do not provide any important source of income yet.
Furthermore, diversification of activities could be used by new farmers to generate an income in the first years after restoration of an abandoned castagnetu. However, to kill two birds with one stone, diversification of *the system* (the castagnetu) rather than diversification of *activities* alone would be especially effective to ameliorate the economic prospects of chestnut farmers. Not only does it provide the farmer with an income during the first years of his/her career as a chestnut farmer, it also enhances the ecological resilience of the castagnetu. For example, the increased structural

complexity of the castagnetu has been shown to prevent the spread of ink disease (Martins *et al.,* 2007). Therefore, by enhancing the resilience of the castagnetu, the farmer also enhances his/her livelihood resilience.

Politically, a change in the allocation of the subsidies from the CAP is recommended by diverse stakeholders; more resources should be made available to support the chestnut sector, which is regarded as one of Europe's most ecologically sound agricultural sectors. The new CAP is currently being revised and will stimulate sustainable farming and ecosystem service delivery by farmers more than it did in the previous period. One change that would benefit new chestnut farmers, would be a replacement of the current income support of farmers based on area alone with a payment system that supports a provision of public goods (ecosystem services) by farmers, as proposed recently by Pe'er *et al.* (2020).
As the chestnut agroforestry system is an agricultural system that provides numerous ecosystem services such as carbon sequestration, erosion prevention (when the castagnetu are well-managed) and biodiversity conservation, chestnut farmers would receive a lot of support if such a CAP change would be implemented. Therefore, CAP changes, such as the suggested one described above, can accelerate the restoration process, since economic challenges are among the most important hurdles that need to be overcome by new farmers.

4.2 Interactions between actors that influence the restoration process

The multi-actor perspective framework helped to uncover the presence of several different actors that influence the restoration, and consequently, the existence of topics that resulted in different visions on how to approach a large-scale restoration **(Fig. 3)**.

The two most important topics of conflicting visions that could impact the restoration are:

A) large-scale versus small-scale chestnut farms as desired future farm size.
B) the exclusive financial support of professional chestnut farmers versus making financial resources also available to non-professional castagnetu owners.

Because of the looming ecological problems that will destroy most abandoned chestnut trees in the coming decades if no large-scale restoration is achieved, there is a dire need to mobilise all actors and resources involved in the restoration process. Conflicting visions could exist without causing any problems as long as they do not reduce the collaboration and coordination between different actors because that is what is needed to achieve a large-scale restoration.
Therefore, the existence of these different visions between actors might be problematic considering the traditional Corsican family-focused culture that prevents cooperatives from working well. It is, hence, questionable if the different actors will succeed in organising a collaborative and coordinated restoration and therefore, this non-collaborative cultural trait might be a crucial factor preventing a large-scale restoration.

4.3 Study limitations and future research

Because of Covid-19 and the lack of online availability of most chestnut farmers, it was impossible to organise a workshop to discuss the results of the research with all participants. This is a missed opportunity because a workshop would have been a good opportunity to discuss with all the actors the different visions and roads to a large-scale restoration. Discussions between different actors about the different roads to follow would have been helpful to better understand the prevailing visions and how exactly the existence of these visions could impact the restoration process.

Furthermore, the lack of conventional chestnut farmers in the interviews (because virtually all Corsican chestnut farmers are AOC-certified (AOCfarinedechâtaignecorse, n.d.)) was a missed opportunity for this research to compare how the production methods impact the ecological problems, as conventional farmers can use hybrid chestnut varieties and potentially use pesticides or other chemicals to treat some of the ecological problems.

Future research should investigate in detail the diversification of castagnetu because system diversification appears to be a solution that tackles multiple problems (the ecological vulnerability, the economic vulnerability and the lack of income during the first years of restoration). The most interesting (economically viable and ecologically adapted) crops should be investigated in Corsican castagnetu to find out how they perform under the local conditions.

5. Conclusion

The restoration of Corsica’s abandoned castagnetu is hindered by a diversity of ecological, social-cultural and economic-political processes and challenges. Because most ecological problems can be controlled with human intervention, the key to achieve a large-scale restoration is the involvement of the Corsicans. Currently, hardly any Corsicans will or can contribute to the restoration of the abandoned castagnetu, due to social-cultural and economic obstacles such as access to land and poor economic prospects. These issues should be addressed quickly and increased financial support for starting farmers and non-farming owners of abandoned castagnetu is vitally important. Besides making more financial resources available, access to the abandoned castagnetu should be facilitated to allow new farmers to start their restoration activities.

Furthermore, the restoration is influenced by a multitude of actors who have sometimes conflicting visions about how to achieve a large-scale restoration. Despite these different visions, a collaborative and coordinative approach is required, involving as many actors as possible, in order to save as many abandoned chestnut trees as possible. It is questionable if such an approach can be achieved because of the failure to organise cooperatives in Corsica due to the non-collaborative (in a non-familial context) cultural trait that characterises Corsican culture.

One important remaining question to be explored is how to realise a diversification of the castagnetu, which is a method to enhance the ecological resilience of the castagnetu and to enhance the farmer’s livelihood resilience. Different crops could be used to diversify the castagnetu but long-term field trials in the castagnetu are required to investigate the ecological suitability and the economic viability of each crop to find out which crops are most promising to use.

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Declaration of interest statement

The author declares no conflicts of interest.

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Appendices

Appendix A

Historical development of Corsica's chestnut agroforestry system

The Corsican region *"Castagniccia"* has been the heart of Corsica's chestnut civilisation for centuries. This microregion of around 50 communities is oriented in the north-east of the island and can best be described as a huge extended castagnetu because of the abundance of chestnut trees that cover the mountains of this region (Perry, 1984; Smith, 2013). A focus on this region is used (because of the relatively good availability of data for this region) to describe the historical developments of the chestnut civilisation, which is symbolic for the development of the chestnut culture on the whole island.

Some of the most densely-populated chestnut-dependent cantons of Castagniccia were Piedicroce and La Porta and in these cantons more than half of the cultivable land was devoted to chestnuts (Perry, 1984). Population densities of these cantons peaked in 1851 and 1886, respectively, but in 1962, the population density was only 37% (in the case of Piedicroce) and 55% (La Porta) of the maximum population a century earlier (Perry, 1984). This rapid decline in population density is symbolic for the shift in prosperity and political importance of Castagniccia; in the 18th and beginning of the 19th century, Castagniccia was the political and economic heart of the island. The commercial chestnut cultivation provided many people with work and was at the heart of the prosperity of the region. However, starting around the 1850s, Castagniccia rapidly depopulated and lost most of its political and economic power, which shifted more towards the coastal regions (Perry, 1984).

It is not easy to point towards *the* ultimate reason for this change, but several factors have been mentioned in literature.
First of all, many Corsicans had family living on the continent (France) and especially the wealthier families preferred to send their children to schools in mainland France, so many children did not go back to Corsica after their studies but stayed in mainland France for work (Perry, 1984). Also, the economic development of mainland France made many Corsicans move to the continent in search for jobs (even though employment rate was high in Castagniccia due to the chestnut industry) (Perry, 1984).
Furthermore, an increased demand for chestnut export in combination with a low potential for agricultural expansion (because most of the cultivable land was already occupied) contributed to the depopulation of Castagniccia. Because many artisans and merchants working in Castagniccia part of the year had large networks in continental France, many of them decided to go to the continent to look for places with (in their eyes) more future potential (for expansion)(Perry, 1984). F
Furthermore, at the beginning of the 20th century, with the opening of the Corsican rural society to a more industrial economy, decaying chestnut trees (partly felled by ink disease, which will be discussed in depth later, partly felled by old age) were sold to the tannin industry. Suddenly, the chestnut trees were felled to make money (Michon, 2011). A last reason for the decline was World War I and II. Many Corsican men were sent to war during World War II, and because many of them did not return, many castagnetu started being abandoned (Perry, 1984).

At the end of the 20th century, initiatives arose to reclaim and restore the abandoned castagnetu (Michon, 2011). Young Corsicans started renovating abandoned orchards, and this led to an increase in production again (though far from the historical maximum production).

However, two years after the accidental introduction of the chestnut gall wasp on the island in 2010, production levels started to decrease sharply and decreased with around 76%, from 637 tons in 2012 to 150 tons in 2014 (DRAAF Corse, 2018; Mansot and Castex, 2018). The most recent figures show that in 2018, production was down to 107 tons (DRAAF Corse, 2019a).

Around the peak production in Castagniccia, around 1830, it is estimated that Castagniccia alone produced 135 000 hectolitres of chestnuts, equivalent to 13 500 tons of chestnuts (Robiquet, 1835). Unfortunately, reported production levels varied unrealistically between consecutive years: in 1902 only 14 000 tons were registered while in 1904, 74 100 tons were registered (Perry, 1984).
For Corsica as a whole, at the beginning of the 20th century, data seem less fluctuating and more reliable than for Castagniccia. In 1924, Corsica was reported to produce 90 000 tons, 95 000 tons in 1925, and 95 000 tons in 1926 (Smith, 2013).
So, based on the 95 000 tons per year, reported by Smith (2013) for good years at the start of the 20th century, the whole Corsican harvest of 107 tons that is left in 2018 *is just 0.11% of the golden years' 95 000 tons*.

Besides the losses in productivity, a substantial decline in the area of managed castagnetu has happened as well. In the 18th century, a maximum of around 35 000 ha of castagnetu was harvested on the island (DRAAF Corse, 2017). After the collapse of the system, it was estimated that there were around 25 000 – 30 000 ha of abandoned castagnetu left that could be brought back into production (DRAAF Corse, 2017). In 2017 however (after the initial revitalisation movement that started in the 1970s), only 1 350 ha were harvested and actively managed (DRAAF Corse, 2018), so more than 20 000 ha of abandoned castagnetu could theoretically be exploited again.

Appendix B

An exploration of two different diversification strategies

I Shiitake production in castagnetu

Introduction

This example serves as a rough guide to the cultivation of shiitake mushrooms in castagnetu. By no means does it serve to give an exact indication of the expected costs and benefits.

Several publications about the small-scale production of shiitake mushrooms on logs were studied and based on the numbers indicated in these documents, data that applied to the Corsican case was chosen. For example, one of the cases was about American shiitake growers who earned as much as €25 per kg for their fresh shiitakes (Mudge *et al.*, 2013). Based on the European market, this price is too high. Therefore, the price was adjusted to a more realistic price for the European context. Two scenarios (€10 and €15 per kg) were compared to understand better the impact of the price on the profitability of this diversification strategy.

Most assumptions and data in this example are based on data obtained from 21 small-scale shiitake growers who inoculated 100 logs for five years in the north-eastern United States (Mudge *et al.*, 2013). The time requirement, costs and profit of these 21 small-scale growers were carefully documented, and therefore, this report provides a unique insight into the small-scale cultivation of shiitake on logs. The reported data were extrapolated to ten years (the researchers published data for five years), assuming a constant production in year six-ten like the production in year five. All the data used can be found in **Fig. 7.**

It is not possible to directly translate these American findings to the Corsican context. However, after reviewing several of the limited data on shiitake log cultivation, it turned out that these data were quite similar (the establishment costs, annual maintenance costs) and it was therefore decided to use the data as a rough estimation (Mudge *et al.*, 2013; Sabota, 2007; Szymanski *et al.*, 2003). Therefore, please regard this example as a rough guide, showing the process and the estimated costs and benefits. For a more detailed explanation about the figures, please consult the original papers where this example is based on (see bibliography) and **Fig. 7**.

Market possibilities

One of the major drawbacks to the cultivation of shiitake might be the unfamiliarity; because the shiitake turned out to be a somewhat unfamiliar food for most participants, it could be challenging to sell the mushrooms at first. It turns out that the consumption of shiitake is not ingrained in Corsican culture and therefore considerable efforts are required to find buyers of the product. However, the abundance of tourists and restaurants in Corsica offers a great way to sell the mushrooms for a good price as the shiitake is a relatively popular food item these days because of its medicinal value in many countries (except Corsica).

Assumptions

- every year for ten years, 100 logs are inoculated. In year five and later, around 371 logs are in production annually (Mudge *et al.*, 2013).
- 3% of logs are culled each year (Mudge *et al.*, 2013).
- irrigation water is available.
- no paid labour, all work done by the farmer.
- logs are bought for €1 per log (eight-twelve cm diameter, sweet chestnut or oak wood) (Mudge *et al.*, 2013; Szymanski *et al.*, 2003).

- logs produce for four years (so lifespan of five years) with average lifetime production of max two kg fresh weight shiitakes (0.5 kg annually from year two-five) (Mudge *et al.*, 2013).

Description of activities

The cultivation of shiitake mushrooms (*"Lentinula edodes"*) on logs in the shade of (chestnut) trees in the castagnetu. Logs are bought and inoculated with shiitake inoculant (spawn) bought from a company **(Fig. 1).**

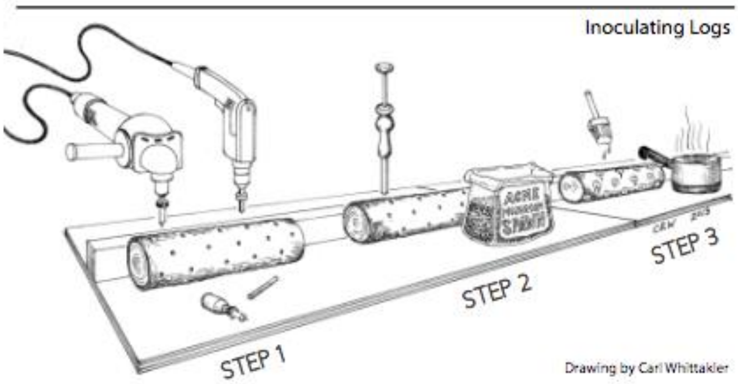

Figure 1. Inoculation of logs. From Sabota (2007).

The inoculated logs will be stacked in a *"laying yard"* during the first year when the spawn run occurs **(Fig. 2).** This is a specific area in the castagnetu that provides sufficient year-round shade, and this is very important to prevent the logs from drying out too much (Sabota, 2007). Availability of water needs to be ensured to keep the logs moist in summer (Sabota, 2007). In the castagnetu, it is required to include some evergreen species because chestnuts cannot protect the logs in early spring and late winter from the sun's radiation (no leaves present yet).

One pile can consist of around ten logs, so a small activity of 371 in full production can, approximately, make 38 stacks. With a surface area of around one m^2, it takes only about 100 m^2 (with space in between to walk), or $1/100^{th}$ ha of castagnetu to place the logs.

Figure 2. Stacking of logs. Source: Mudge *et al. (2013).*

The logs start fruiting in the second year and remain in production for four years.

Logs need to be 'shocked' by putting the logs in water (tanks) for a minimum of 24 hours (two or three times per year) to stimulate fruiting (Mudge *et al.*, 2013; Sabota, 2007). Therefore, a system to have water available close to the fruiting place is important. This can be a roof-water collection system (Sabota, 2007), or irrigation from a source.

In the two weeks following soaking, the logs are stacked (A-frame stack, see **Fig. 3** (Sabota, 2007)) in another shaded area of the castagnetu and harvest takes place during these weeks.

Figure 3. Fruiting of logs: after shocking the logs they are A-frame stacked to promote good aeration. Source: Mudge *et al* (2013).

Materials and estimated costs

In total, the costs for the first year (establishment & annual materials such as spawn and logs) are (assumed to be) €1 028 (Mudge *et al.*, 2013). Costs for year 2-5 are around €537 (Mudge *et al.*, 2013). The ten-year costs are around €6 124. As shown in **Table 1,** only several tools are needed. Therefore, this enterprise diversification is cheap to establish. Furthermore, chestnut farmers already own several of the required tools.

Table 1. Necessary materials and costs (Mudge *et al.*, 2013; Sabota, 2007; Szymanski *et al.*, 2003).

Chainsaw	Chainsaw sharpening
Inoculation tool	Logs
Sawdust spawn	Wax
Angle grinder	Angle grinder charger
Drill	Drill bit
Generator gasoline	Shade cloths
Water tanks	Fuel for transportation
Labelling/packaging material	Other durable/non-durable materials

Time requirement and synchronisation with chestnut related activities

An average of 129 person-hours per year is required over the ten years (Mudge *et al.*, 2013). From year five onwards (full production), annual time requirement (a single person) is 152 hours **(Fig. 4).**

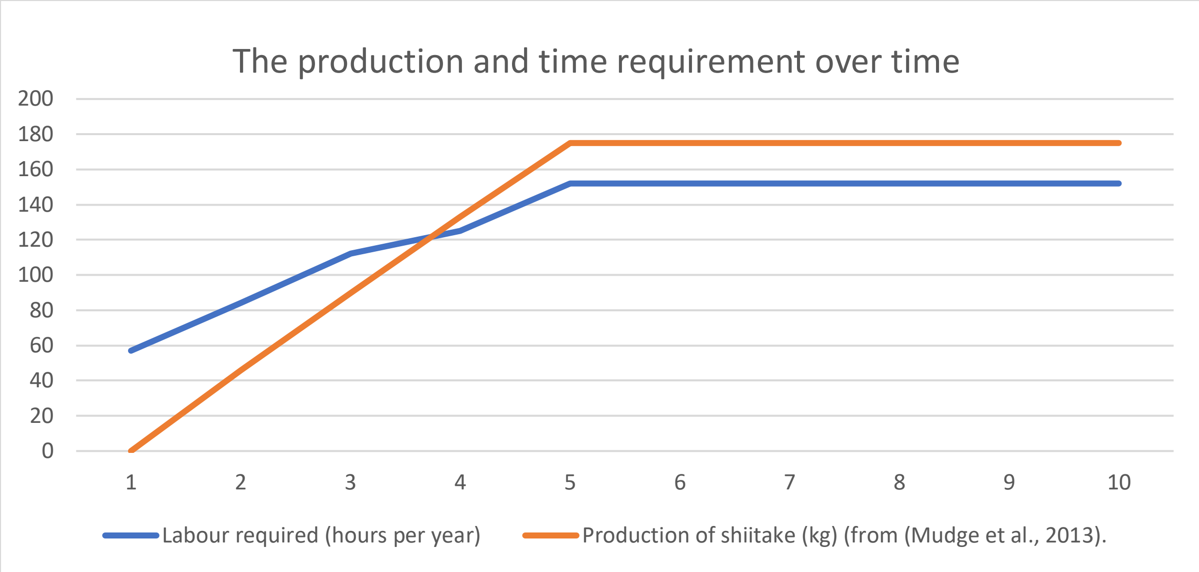

Figure 4. Simulation of the productivity and the labour requirements over a ten-year simulation period.

Expected profits

0,47 kg shiitake per log per year on average over the lifespan of a single log (five years) with a total production of maximum two kg (Mudge *et al.*, 2013) can be expected (conservative estimation). At maximal productivity of the business (year five to ten), 371 logs are fruiting (Mudge *et al.*, 2013). Two situations are considered:

- selling shiitake for a relatively low price of €10 per kg to stores.
- selling shiitake for a high price to restaurants and on farmer markets (€15 per kg).

Scenario 1: €10 per kg sales to stores

In the first example, in ten years, an annual net profit of €707 is accomplished (includes all expenses, **Fig. 5).** When reaching full production in year five, the average net salary for the following years is around €8 per hour with an annual average net profit of €1 213. After ten years, the net cumulative profit is €7 066.

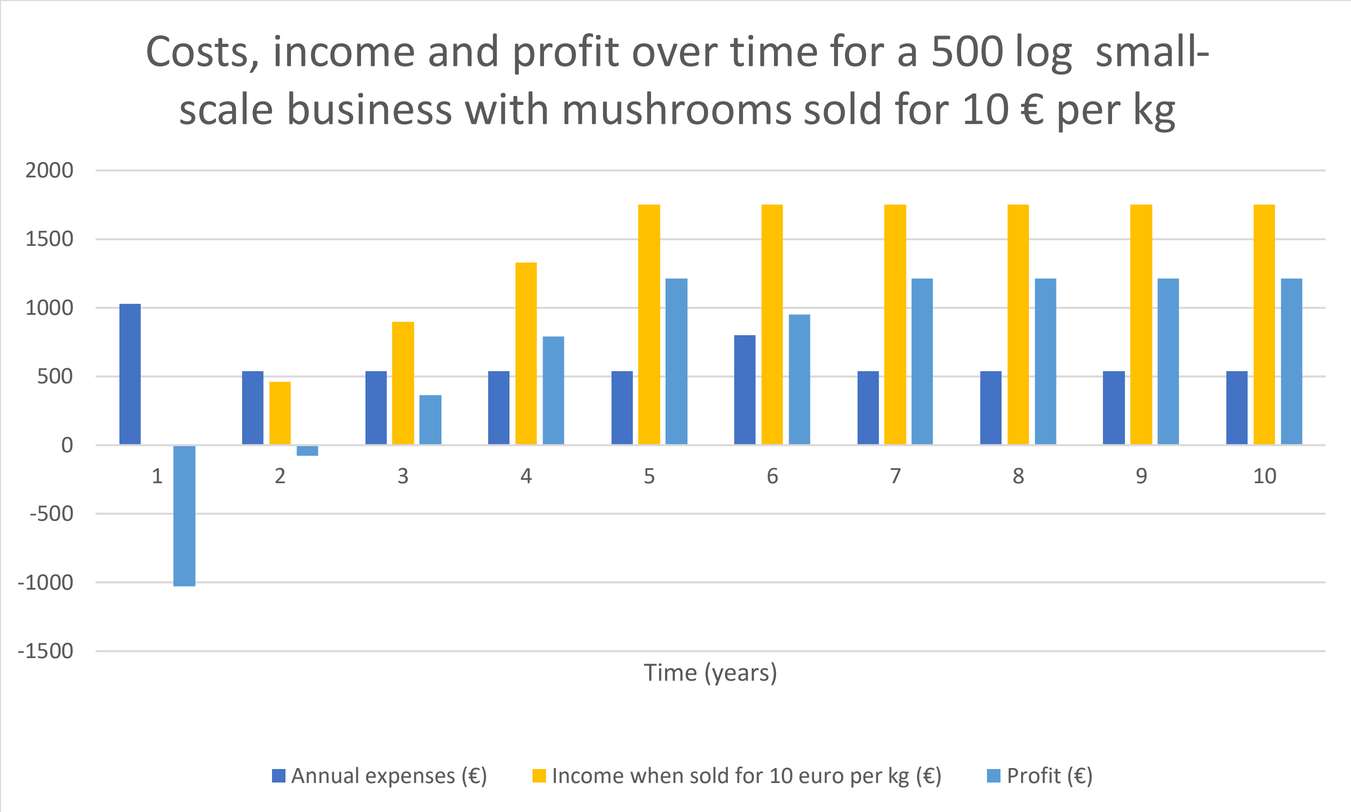

Figure 5. Simulation of the costs, the profit and the income over ten years.

Scenario 2: €15 per kg sales to restaurants and on farmer markets

When focussing on restaurants and farmer-markets, shiitake can be sold for a higher price. In this calculation, €15 per kg was assumed. With this assumption, an average annual profit of €1 366 over the ten years is realised. When reaching full production in year five, average net salary for the following years is around €13.74 hour^{-1} with a yearly income of €2 088. After ten years, the cumulative net profit is €13 661.

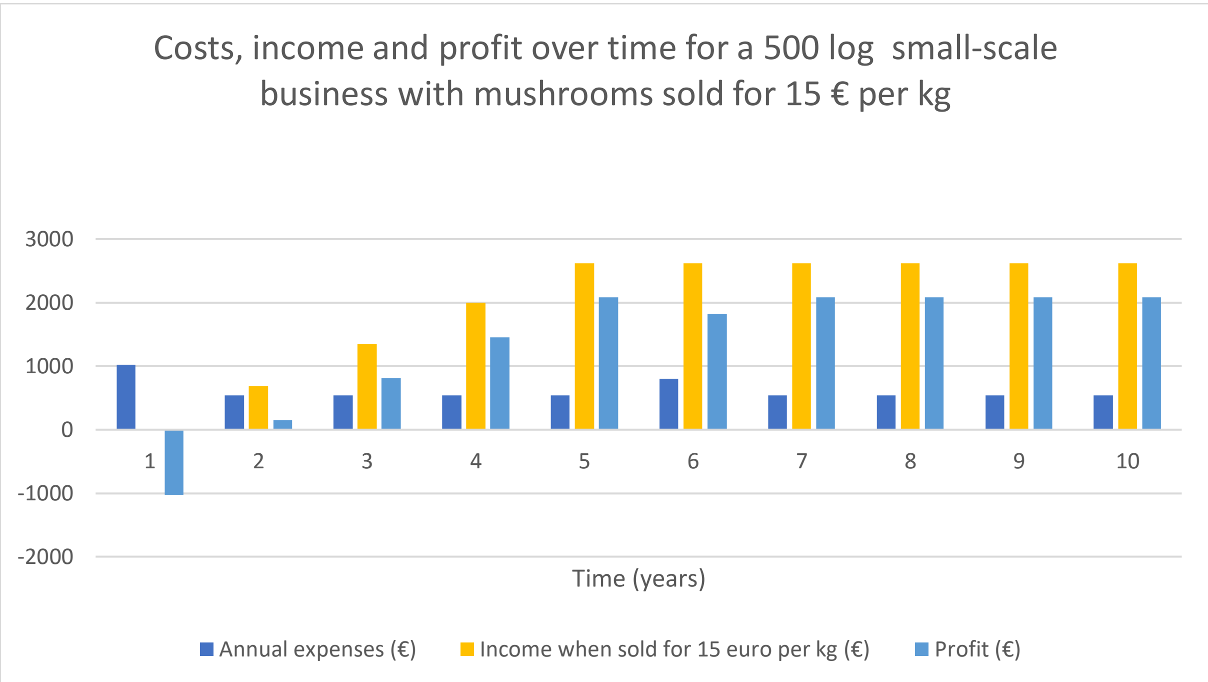

Figure 6. Simulation of costs, profit and income over ten years.

Conclusions

The second scenario shows that after five years, the annual profit rises to €2 088. This is not enough to compensate for a substantial decline in chestnut production in a future theoretical situation. However, it must be acknowledged that the time spent on this activity is only 152 hours per year which means that, if the chestnut farmers think this is compatible with the chestnut related activities, an increase in the production of shiitake could be a possibility to increase profit and reduce the economic impact of a crash in chestnut production.

For example, it could be possible to triple the number of logs in production (1 500). This would result in annual maximum production of 525 kg of shiitake, resulting in an annual maximal profit of €6 264 (the expenses triple as well). This profit is already quite substantial for a chestnut farmer during bad times.

						salary per hour					
Based on these numbers (from p. 52 onwards)						7,9802632					
https://www.uvm.edu/sites/default/files/media/ShiitakeGuide.pdf			**10 € per kg** scenario								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	annual
Annual expenses (€)	1028	537	537	537	537	800	537	537	537	537	**612,4**
(Mudge et al, 2013) states 1041 dollar. =928 €	**Costs year 2-5: 490 dollar reported by Mudge et al, 2013; in € and considering buying 100 logs, costs are 437€ +100€=537€**										**129**
However, in contrast to Mudge et al, 2013, we assume the logs are bought for						**Costs year 6 are higher because of renewal of certain broken machines**					
1€ each (100 logs per year). Total costs are: 928€ + 100€= 1028€ first year											
Production of shiitake (kg), from (Mudge et al, 2013)	0	46	90	133	175	175	175	175	175	175	**131,9**
Income when sold for 10 euro per kg (€)	0	460	900	1330	1750	1750	1750	1750	1750	1750	**1319**
Profit (€)	-1028	-77	363	793	1213	950	1213	1213	1213	1213	**706,6**
Year	1	2	3	4	5	6	7	8	9	10	
Labour required (hours per year)	57	84	112	125	152	152	152	152	152	152	
Production of shiitake (kg) (from (Mudge et al., 2013).	0	46	90	133	175	175	175	175	175	175	**131,9**
			15 € per kg scenario:								
	expenses 10 years	6124									
Year	1	2	3	4	5	6	7	8	9	10	
Annual expenses (€)	1028	537	537	537	537	800	537	537	537	537	**612,4**
Income when sold for 15 euro per kg (€)	0	690	1350	1995	2625	2625	2625	2625	2625	2625	**1978,5**
Profit (€)	-1028	153	813	1458	2088	1825	2088	2088	2088	2088	**1366,1**
		Salary (€/h)	13,736842								
10 year net profit 15 euro per kg	**13661**										
10 year net profit 10 euro per kg	**7066**										

Figure 7. Raw data used for the simulations of shiitake. Based on the work of Mudge *et al. (*2013).

II Hazelnut

Introduction

The following example is based on the best available data on hazelnut production in France but must be regarded only as a rough estimation; it is impossible to accurately estimate the costs in the Corsican case without doing a detailed study. This study aims to investigate the possible implementation of this diversification strategy and because one of the important factors is economic viability, an economic scenario for this diversification plan was explored.

Background

Hazelnut (*Corylus avellana*) is a tall bush that has been cultivated for its nuts in Corsica since the beginning of the 20th century (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014).

Ecological suitability

In particular, the *"Noisette de Cervione"* or its true varietal name *"Fertile de Coutard"* is well-adapted to the local north-eastern climatological conditions of the island (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014).

Furthermore, most dominant pests that plague hazelnut growers in mainland Europe are not present in Corsica, making the production easily compatible with organic production requirements (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014).

Establishment of new hazelnut groves should ideally be done on north-east facing slopes because this orientation limits summer evapotranspiration which is required for a good development (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014). Furthermore, hazelnut groves on north-east facing slopes are subject to low winter temperatures which is a condition required by many temperate crops for a successful development (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014).

Description of activities

Here, the cultivation of hazelnuts bushes integrated into a castagnetu is considered. The idea is that several old diseased chestnut trees are cut and replaced by hazelnut bushes. After planting the bushes, annual fertilisation and irrigation can be applied, though in general hazelnuts are well-adapted to a wide range of soil types and, if planted on a north-east oriented slope, are quite low-demanding (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014). Harvest of hazelnuts starts around the end of August and takes several weeks, including the drying process. Hazelnuts are then sold (in the shells) to the *"Atelier de la Noisette"* which is a company that cracks the nuts and processes them.

Market demand and opportunities

In Corsica, there is a growing market for hazelnuts. Last year, the nutcracker factory of Cervione, which works with 150 producers and cracks 80 tons per year, paid farmers €2.80 per kg hazelnuts (Bouschon, 2019). It is because of the IGP accreditation (geographical production certification) obtained by the hazelnut of Cervione that producers can obtain such high prices. The *Atelier de la Noisette* in Cervione processes 60 tons and requires 120 tons to fulfil the demand, suggesting that there is a window of opportunity for more hazelnut production (Bouschon, 2019).

Synchronisation with chestnut related activities

Hazelnut harvest takes place in August and September, which is the period when the preparations (September) for the harvest (October and November) of chestnuts is being done (Ritchie, 2008). Therefore, there is some overlap, but most of the hazelnuts are already harvested when the chestnut harvest period begins.

Example: 3 hectares of hazelnuts de Cervione

In this example, three hectares of Cervione hazelnuts are planted. The hazelnuts are planted in castagnetu and replace old diseased chestnut trees that are cut. In this example, a castagnetu of nine ha is considered. On each hectare, one-third of the chestnut trees (the diseased ones) is cut to create a castagnetu that is more diverse (because hazelnut bushes are planted as a replacement for some of the old chestnut trees). Therefore, three ha of hazelnuts is integrated in nine ha of castagnetu.

A schematic illustration of this is shown in **Fig. 7.** The density of traditional old castagnetu is about 45 trees ha^{-1}. By removing about one-third of the trees, there is space for around 116 hazelnut bushes. A typical hazelnut monoculture plantation contains 350-400 plants (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014). Therefore, one-third of 350 is around 116 plants ha^{-1}. In the case of the former nine ha castagnetu, the renovated nine ha could look like **Fig. 7.** In this example, hazelnut bushes were grouped to increase harvest and management efficiency, while still forming an ecological barrier between the chestnut trees, which might be beneficial to reduce disease spread in the orchard.

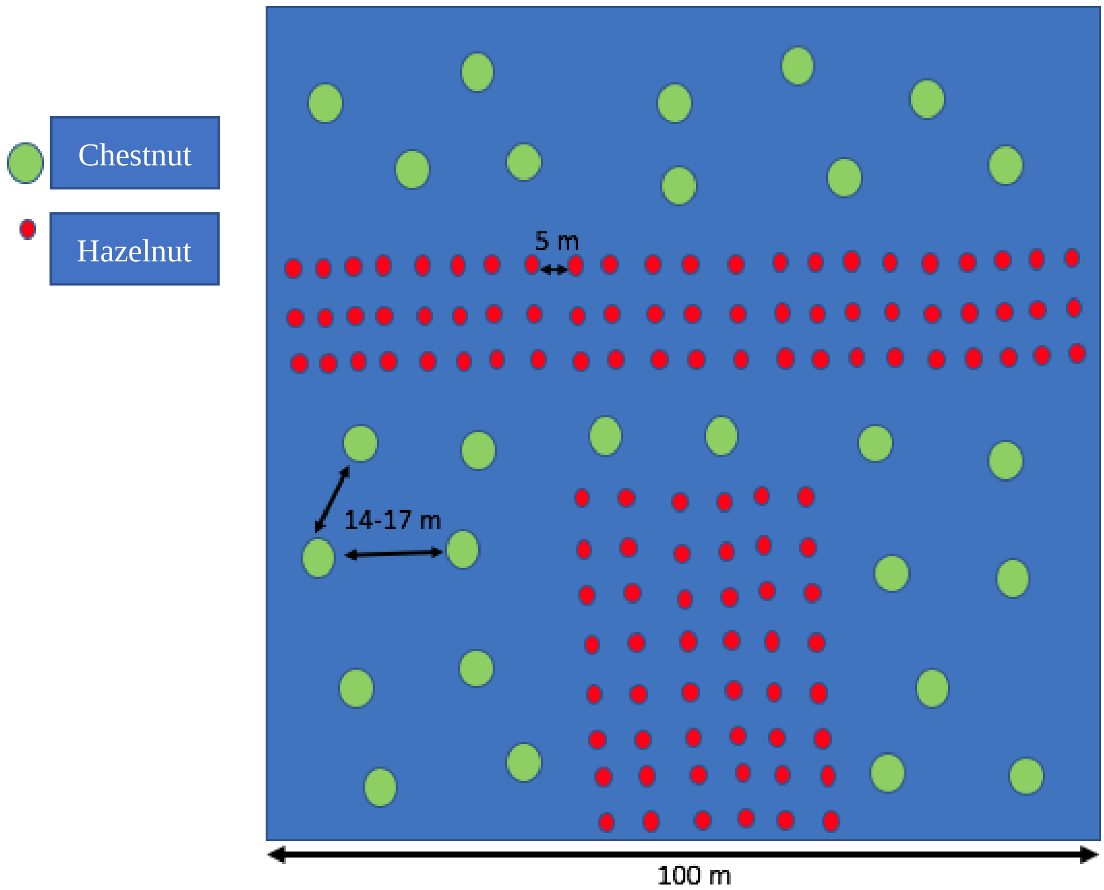

Figure 7. Schematic illustration of the design of a hectare diversified castagnetu.

Assumptions

- **establishment costs per hectare** are in the range of €10 500 - €16 200 ha^{-1} (Ritchie, 2008; Association casse noisettes, 2017b; Association casse noisettes, 2017a). **€11 700** is used and is based on the data provided by Association casse noisettes (2017b). This includes all materials to manage the bushes, the hazelnut bushes themselves, subscription to local cooperatives and other necessities.

- **annual maintenance costs are €1 572 ha^{-1}** which are the costs provided by Association casse noisettes (2017a) adapted to the local Cervione context (assuming half the inputs as compared to the reference data set which is not specified to the local Cervione variety) because of the low-input cultivation of Cervione (and consequent lower yield).
- **labour** (trimming of bushes, plantation) **is done by producer and family.**
- **the price per kg received by a farmer is €2.80** which was the most recent price paid by the nutcracker factory of Cervione (Bouschon, 2019).
- **the maximal productivity in a monoculture is 1 250 kg ha^{-1}** (350-400 bushes maximally ha^{-1}) which is relatively low productivity of 3.1-3.6 kg per bush, hence this is a conservative estimation (Ritchie, 2008). This number is an arbitrary number chosen after considering several documents about hazelnut yields, which suggested average yields for Limousin growers are expected to be 2.5 tons ha^{-1} (Association casse noisettes, 2017b) while Canadian growers can expect yields of more than 4 tons per hectare (Ritchie, 2008).
  In short, there is large varietal heterogeneity in production, and therefore, it is hard to make accurate estimations of the yield expected for Cervione hazelnuts. Based on the scientific data mentioned above, based on personal experiences with hazelnut growers in Corsica, data provided by the local newspaper (Bouschon, 2019) and based on the precautionary principle, the conservative estimation of **1 250 kg ha^{-1}** (for a monoculture of hazelnuts) was chosen.
- **at four years, the first harvests can be done** and **max. productivity is reached from year eight** onwards (Association casse noisettes, 2017b).
- **the annual costs are considered constant** (even though more time requirement with higher yields leads to more costs).
- **for 25 years**, data is analysed.

The raw data and explanation for the assumptions can be found in **Fig. 12.**

<u>Outcomes</u>

From year six onwards, annual income is higher than annual costs. From year eight onwards, an income of €10 500 can be expected, which leads to a profit of €5 784 **(Fig. 8 & 9).**

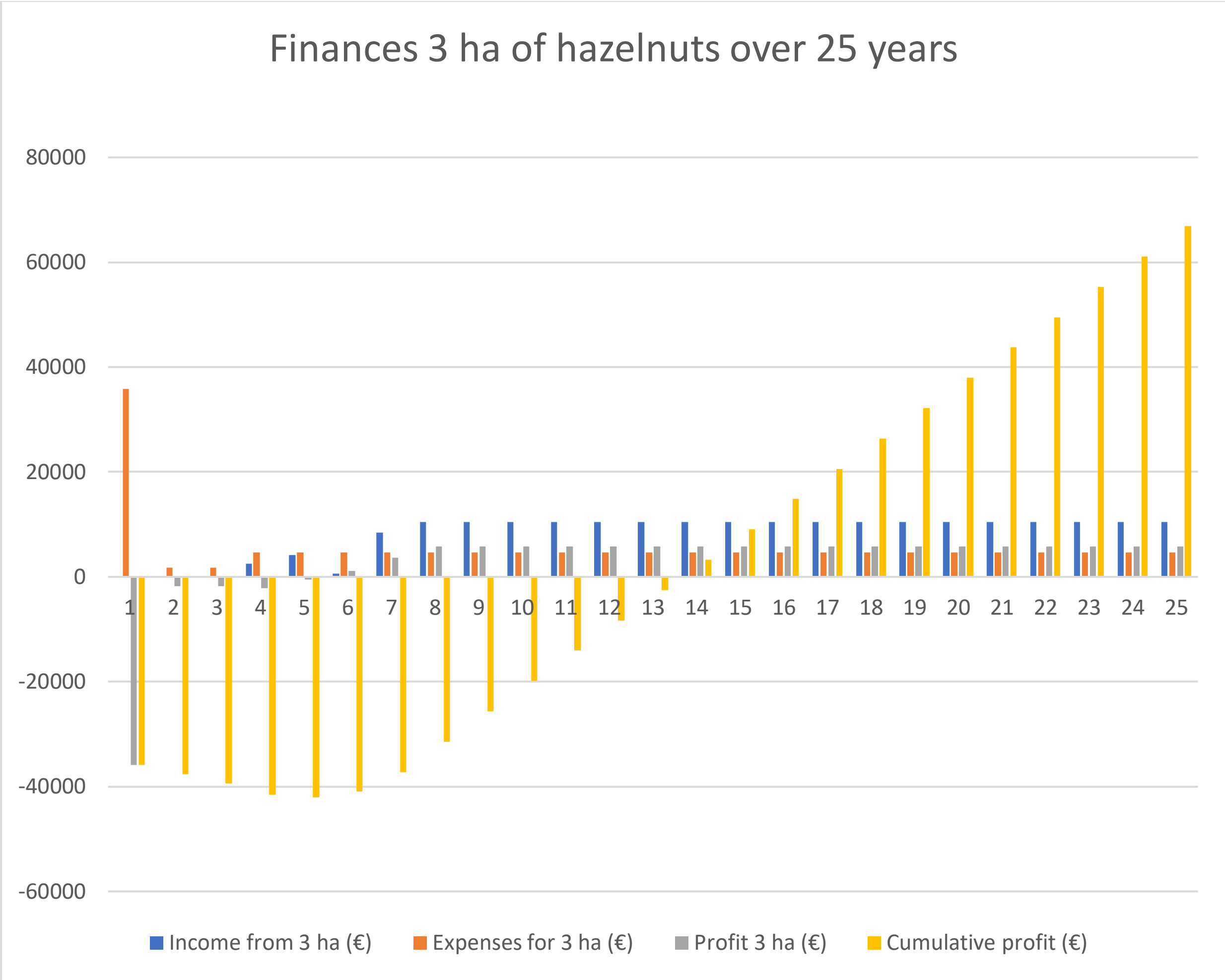

Figure 8. Simulation of annual costs, income and profit and cumulative profit over the 25 years.

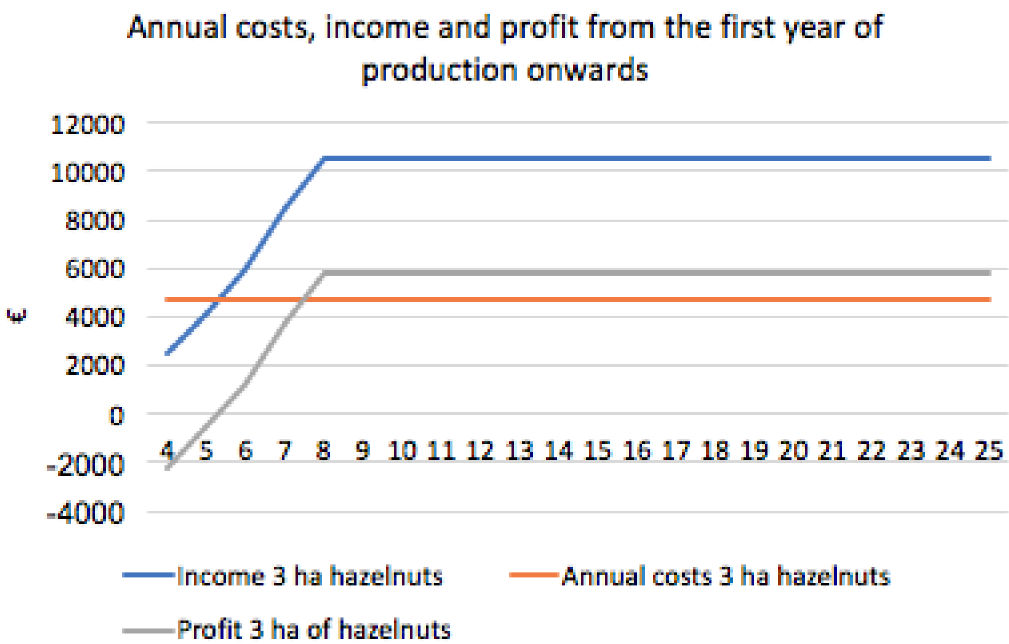

Figure 9. Simulation of the income, annual costs and profit over 25 years.

Prices of hazelnuts tend to be higher than or comparable to prices received for fresh chestnuts, but lower than prices received for chestnut flour. For the production of chestnut flour, five kg of fresh chestnuts were assumed to be required to produce one kg of flour (AOCfarinedechâtaignecorse, 2018).

In 2010, when chestnuts were not plagued by the chestnut gall wasp yet, fresh chestnuts were sold for only €0.85 per kg, while chestnut flour was sold for €7.50 per kg (DRAAF Corse, 2015). In 2015, when chestnut production was very low because of the chestnut gall wasp, prices went up: €2.88 per kg fresh chestnuts and €13 per kg chestnut flour (DRAAF Corse, 2018). This price increase reflected the increased scarcity of the product: in 2010, one hectare produced around 1 460 kg, while in 2015, it produced only 305 kg (DRAAF Corse, 2015, 2018). Compared to this, hazelnuts can be sold for €2.80 per kg (Bouschon, 2019), so they are comparable to fresh chestnuts in very unproductive years **(Fig. 10).**

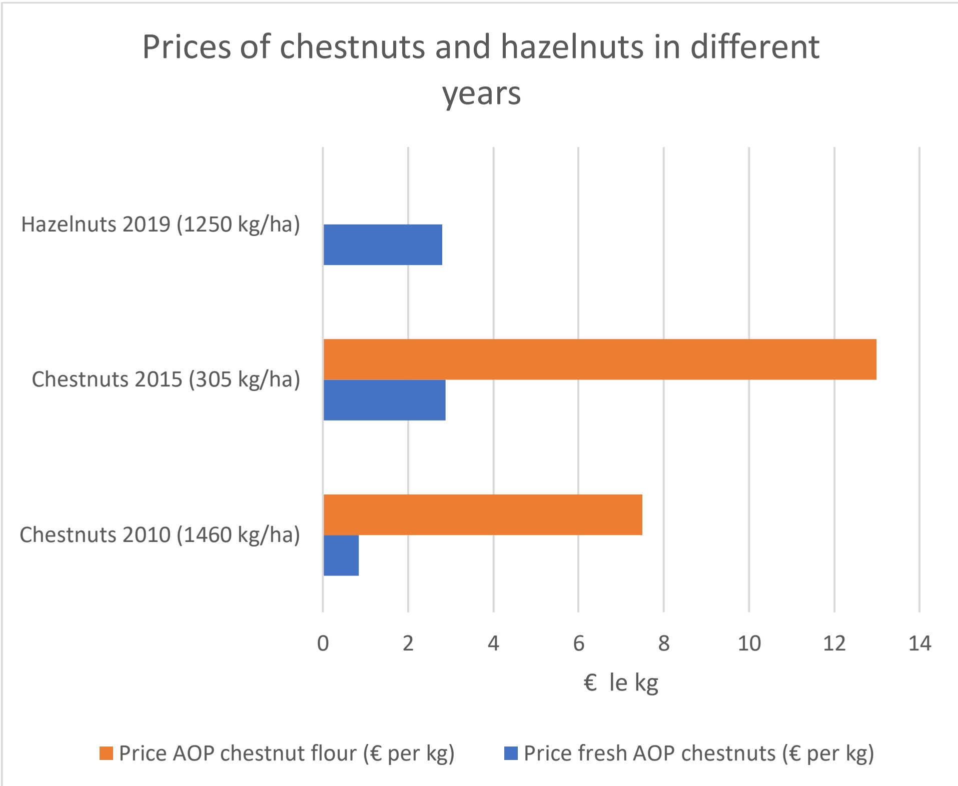

Figure 10. Comparison between the price of AOC chestnuts and Cervione hazelnuts in Corsica.

Furthermore, if we translate these findings into expected income, it becomes clear that hazelnuts have the potential to provide a higher income than chestnuts can provide **(Fig. 11).** The income provided by three hectares of chestnuts, either in full production (1 460 kg ha^{-1} for chestnuts) or in sharply decreased production (305 kg ha^{-1}) is now compared with the income provided by three hectares of hazelnuts in full production (1 250 kg). For chestnuts, the income was calculated either from flour production or from fresh chestnuts. For hazelnuts, only the sales of the non-processed product fresh product were considered.

The results suggest that hazelnuts provide a higher income than chestnuts, even in a productive year (1 460 kg ha^{-1}). Hazelnut income from three hectares was €10 500 per year.

Because no reliable data on the expected annual costs of chestnut production could be retrieved, it was not possible to make a comparison between the *profits* of hazelnuts and chestnuts. What can be concluded is that the profit of hazelnuts in full production (for three ha), where reliable data could be found for, is €5 784 (annual costs for three hectares are €4 716). This is more than the *income* of either flour or fresh chestnuts in 2015 (a lousy chestnut year), and this is more than the income provided by *fresh* chestnuts in 2010 (good productivity). However, it is less than the income provided by chestnut flour in 2010 (€6 570) but, as noted before, the production costs could not be verified. Very likely, with the production costs for three hectares of chestnuts included, the resulting profit is lower than the profit for hazelnuts (€5 784).

In this example of a total of three hectares of hazelnuts integrated into a castagnetu, it takes fourteen years until a farmer has earned enough to compensate for the initial (year one) investment costs and the fourteen year-long annual costs.
In the last year of this simulation (year 25), a cumulative *profit* of €66 885 is reached. This means that over these 25 years, with the investment costs included, the *average annual profit* is €2 675 (for the three ha). Over a 22-year period starting in year four (first year of production), the average annual profit is €4 830 (for the three ha) (because the first year's investment costs are not included here).

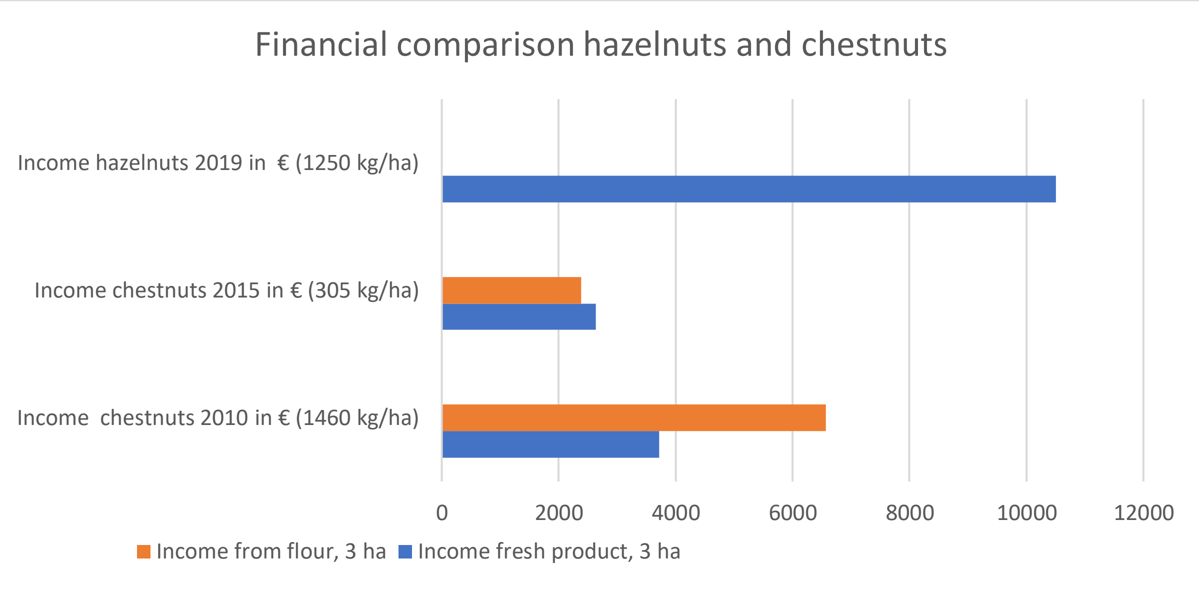

Figure 11. Comparing hazelnuts with chestnuts, either flour or fresh product.

Concluding, this comparison aimed to investigate if the replacement of three hectares of chestnut trees with hazelnuts would have a negative financial impact on a farmers' livelihood. These data suggest that this is not the case; in contrast, these data suggest that the cultivation of hazelnuts might actually provide higher profits than monoculture chestnut production when considering full production. To put these findings in perspective, it must be stated that the establishment costs of three hectares of hazelnuts are a serious investment of around €35 000.

However, the productivity of other varieties (not the Cervione hazelnut) can be much higher than the 3.1 to 3.6 kg per plant reported for the Cervione hazelnut. Based on scientific data (Ritchie, 2008) and observations of other hazelnut varieties in Corsica, a production of ten kg per hazelnut could be possible. Therefore, when cultivating 1 044 hazelnut plants of another variety (3 ha of hazelnuts), more than ten tons of hazelnuts can be expected. With the same price of €2.80 per kilo (so no direct sales but selling the hazelnuts to the factory in Cervione), from full production onwards an income of €28 000 per year can be expected (while in this simulation a max. income of €10 500 is assumed, because here the production of Cervione nuts has been considered).

Plantation costs 1 ha	**Preparation orchard**	344										
	Hazelnut plants	4000										
	Fertilisation	876										
	Protection animals	467										
	Irrigation	1450										
	Contribution to COOP	240	**Total establishment costs 3 ha**	35103								
	Starting rights	228										
	"Cumuls des charges"	4096										
	Total establishment costs	**11701**	**Total establishment costs 1 ha**	**11701**	€/ha							
			Time	1	2	3	4	5	6	7	8	
			Production of 1250 kg per ha of Cervione hazelnuts	0	0	0	300	500	700	1000	1250	
Annual costs 1 ha	**Inputs**	**350**	**Income from 1 ha (€)**	0	0	0	840	1400	1960	2800	3500	
	irrigation	240	**Expenses for 1 ha (€)**	11941	590	590	1572	1572	1572	1572	1572	
	Drying	800	**Profit 1 ha (€)**	-11941	-590	-590	-732	-172	388	1228	1928	
	Harvesting	182	**Cumulative profit (€)**	-11941	-12531	-13121	-13853	-14025	-13637	-12409	-10481	
	Total annual costs	1572	**time**	1	2	3	4	5	6	7	8	
Condition: 50% of the input costs used (compared to data provided by ass. casse noisettes			**Income from 3 ha (€)**	0	0	0	2520	4200	5880	8400	10500	
because of low productivity of Cervione hazelnuts and lower input needs			**Expenses for 3 ha (€)**	35823	1770	1770	4716	4716	4716	4716	4716	
Furthermore, in first 3 years, only input and irrigation costs (because there is no harvest yet)			**Profit 3 ha (€)**	-35823	-1770	-1770	-2196	-516	1164	3684	5784	
			Cumulative profit (€)	-35823	-37593	-39363	-41559	-42075	-40911	-37227	-31443	

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572
1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928	1928
-8553	-6625	-4697	-2769	-841	1087	3015	4943	6871	8799	10727	**12655**	**14583**	**16511**	**18439**	**20367**	**22295**
9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500
4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716	4716
5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784	5784
-25659	-19875	-14091	-8307	-2523	3261	9045	14829	20613	26397	32181	37965	43749	49533	55317	61101	66885

Figure 12. Raw data used for the simulations of the hazelnut diversification.

Appendix C

An overview of the participants that were no professional chestnut farmers

Nine different participants besides professional chestnut farmers were interviewed. The description of theri activities is listed below.

Participant (pseudonym)	Function(s)	Age
8 Léa	Chestnut expert professionally working for chestnut sector.	Forties
9 Camille	Chestnut expert professionally working for chestnut sector.	Fifties
10 Jean-Marc	Young Corsican permaculture farmer with years of experience working in castagnetu.	Twenties
11 Dominique	Farmer with several crops including chestnuts, bees and olives.	Forties
12 Benjamin	Young Corsican aspiring farmer (diversified agroforestry farm) with a background in agroecology and castagnetu.	Thirties
13 Bernard	Professor of Corsica's history from University of Corsica.	Sixties
14 Thibault	Founder of a subtropical Mediterranean food forest in Avapessa with a unique knowledge about agricultural diversification.	Sixties
15 Nicola	Rural development scientist working for INRA Corsica. His expertise is local Corsican food chains.	Fifties
16 Charles	Founder of a self-sufficient community implementing permaculture techniques living in Castagniccia.	Seventies

Appendix D

Questionnaire

<u>Research question 1:</u>

Chestnut gall wasp

- What actions have the professional organisations related to the Corsican chestnut sector taken during the last decade to control the chestnut gall wasp?
- How has the chestnut gall wasp influenced the health and production of the chestnut trees?
- Are there endemic chestnut varieties that better resist the chestnut gall wasp than others?
- What do you think of the use of hybrid varieties?
- How has the financial support program launched to compensate for the loss of production due to the chestnut gall wasp helped you?

Chestnut blight

- What actions have the professional organisations related to the Corsican chestnut sector taken during the last decade to control chestnut blight?
- How has chestnut blight influenced the health and production of the chestnut trees?
- Is there, and if so, what is the connection between the chestnut gall wasp and chestnut
- blight?
- How does the geographic orientation of the orchard (north vs south-facing slope, at high or low altitude) impact the severity of the disease?
- How can the disease be controlled?
- What is, according to you, the best way to prune chestnut trees to control blight?
- Are there any known endemic varieties that are (better) resistant to the disease?
- How do you manage dead wood in your orchard?
- What is your experience with biological control using hypovirulent strains of the fungus?

Ink disease

- What actions have the professional organisations related to the Corsican chestnut sector taken during the last decade to control ink disease?
- How has ink disease influenced the health and production of the chestnut trees?
- What actions, if any, have you taken yourself to control the disease?
- Are there any known endemic varieties that are (better) resistant to the disease?

Climate change

- Have you observed any changes in precipitation, temperature or other climatic factors in the last decades?
- If so, how has this impacted the chestnut trees?
- Do you think the orientation of the orchard impacts the ability of the trees to deal with the predicted higher temperatures and lower rainfall in Corsica?
- Have you considered methods to capture and hold more water on site to cope with the predicted increasingly frequent droughts?
- Can you tell me what you know about the ancient water systems that many Corsican villages had?
- What role can castagnetu play regarding wildfires?

Livestock

- Do you think the abandoned livestock has any impact on the health of the remaining chestnut trees? If so, how does it impact the trees?
- What can be done to protect the orchards from the livestock?

Generational change in production methods
- How do you think the production methods used by the current generation of chestnut farmers differs from those of the previous generations?
- How do you explain these changes?
- What changes concerning the production methods do you think are needed to enable a larger-scale restoration of abandoned orchards?

Productivity
- How has the productivity of chestnut changed in the past decades?
- Which ecological problem has had the most important impact on productivity?
- How has the understory

Future vision
- How do you see the future of the chestnut sector in 10 years?
- How do think the restoration of abandoned orchards will proceed in the coming decade?

Research question 2:

Restoration of orchards
- Which selection criteria should be kept in mind to find the orchards with the highest potential to be restored successfully?
- How long does it take after initial restoration efforts to obtain a reasonable chestnut production?
- Do you regard the restoration cost as an important constraint for the restoration?
- What are the costs related to the restoration of an abandoned orchard (pruning, fencing)?
- What can be done to keep the costs of restoring as low as possible?

Land transmission and access
- Why is the transmission of and access to castagnetu an issue that hinders the restoration of abandoned orchards?
- How to facilitate the transmission of castagnetu?
- What role can local municipalities play to facilitate the access to land?
- What can local, regional or even national or European governments do to stimulate the restoration of the abandoned orchards?
- Are there alternative constructions possible to access land and if so, which ones and how do they work?

Youth involvement
- How do you think Corsica's youth can be stimulated to become chestnut farmers?
- How does the social environment/infrastructure of Corsica's countryside affect the willingness of young Corsicans to become chestnut farmer?

Research question 3:

Need and willingness to diversify
- How do you consider the economic viability of chestnuts as only source of income?

- How do you consider the resilience of the traditional chestnut agroforestry system which is a monoculture of trees?
- Do you think local inhabitants accept a diversification of the castagnetu or do you think they are strongly attached to the traditional monocultural system?
- What can be done to facilitate the process of diversification?

Diversification strategies

- Do you implement any diversification strategies in your castagnetu? If so, which and why?
- Do you know any chestnut farmers who have diversified their castagnetu? What diversification methods do they implement?
- Are there any diversification strategies you are currently considering but have never seen implemented in Corsica?

Shiitake diversification

- Do you think there is a demand for shiitake mushrooms?
- How easy or difficult do you think it would be to sell shiitake mushrooms in Corsica and what could be done to facilitate the sales?
- Is there any overlap between the activities related to the chestnut and those related to the shiitake? If so, when?
- How do you think this diversification strategy is adapted to the local environmental conditions found in the castagnetu?
- What do you think about the economic viability of this diversification strategy?
- Do you have any feedback to improve the feasibility of this diversification strategy?

Hazelnut design

- Do you think there is a demand for hazelnuts in Corsica?
- How easy or difficult do you think it would be to sell hazelnuts in Corsica and what could be done to facilitate the sales?
- Is there any overlap between the activities related to the chestnut and those related to the hazelnut? If so, when?
- How do you think this diversification strategy is adapted to the local environmental conditions found in the castagnetu?
- What do you think about the economic viability of this diversification strategy?
- Do you have any feedback to improve the feasibility of this diversification strategy?

Appendix E

Consent form

The content form that was used for this study (in French) is presented below.

Titre du projet : Revitaliser les châtaigneraies en Castagniccia : découvrir le savoir-faire des castanéiculteurs pour développer une compréhension approfondie des possibilités pour relancer u castagnetu.

Nom du chercheur : Niek Pepels

Durée du projet : 6 mois

Origine du projet
Mémoire de Fin d'études (MFE) de Niek Pepels, étudiant du European Master of Agroecology au sein de l'Université de Wagenigen aux Pays-Bas avec la supervision de l'ISARA (Institut Supérieur d'Agriculture Rhône-Alpes).

Objectifs du projet
Développer une compréhension approfondie des possibilités d'une relance des châtaigneraies en Corse. L'objectif principal est de donner l'occasion aux castanéiculteurs de Corse et à d'autres experts engagés dans la filière castanéicole d'exprimer leur opinion et de partager leur vision et leur savoir-faire concernant les problèmes qui frappent actuellement la filière corse pour mieux comprendre comment on peut résoudre ces problèmes.

Raison et nature de la participation
Ce mémoire étudie la situation actuelle des châtaigneraies en Corse. Vous êtes sélectionné pour participer à cette recherche parce que vous êtes soit un castanéiculteur en Corse, soit un expert de la problématique liées à la châtaigneraie en Corse. Pour réussir à mieux comprendre les opportunités de revitalisation des châtaigneraies de la Corse, cette étude essaie de réaliser des interviews avec les castanéiculteurs de Corse.

Inconvénients à participer à cette étude
Le seul inconvénient à votre participation à cette recherche est le temps consacré à l'entrevue.

Avantages à participer à cette étude
Votre participation vous permettra d'exposer vos opinions et de partager votre savoir-faire concernant l'entretien des châtaigneraies et cela contribue à l'amélioration des connaissances scientifiques concernant la revitalisation de la châtaigneraie corse. Aussi, votre participation vous permettra de mieux comprendre les méthodes de revitalisation des châtaigneraies de Corse proposées par vos collègues en échangeant avec le chercheur.

Mesures et engagements à la confidentialité
Les informations que vous donnerez seront confidentielles. Seuls le chercheur et ses superviseurs de l'université de Wageningen et de l'ISARA pourront avoir accès à l'enregistrement de l'interview. Le chercheur pourra utiliser les informations données dans son MFE à condition que ces informations restent anonymes et qu'il soit impossible d'identifier qui en est l'auteur (sauf si le participant permet d'utiliser son nom). L'interview sera enregistrée et sera seulement accessible au chercheur et ses

superviseurs pendant la période de recherche dans un compte Google Drive. Le contenu de l'interview (versions papier et audio) sera détruit à la fin de l'année.

Coûts et rémunération
Aucune rémunération n'est prévue pour votre participation à cette étude.

Diffusion des résultats
Les résultats de cette étude seront présentés à l'université de Wageningen aux Pays-Bas, l'ISARA (Institut Supérieur d'Agriculture Rhône-Alpes) à Lyon et la Chambre d'Agriculture de Haute-Corse à Bastia. Évidemment, l'étude sera transmise aux participants (principalement des castanéiculteurs) de cette étude. Un rapport écrit sera disponible en Anglais et en Français à partir de la fin juin. Le chercheur enverra le rapport à tous les participants ayant une adresse email. Les castanéiculteurs qui n'ont pas d'adresse e-mail peuvent aussi contacter le chercheur par téléphone pour discuter d'une méthode alternative d'accéder au rapport.

Votre consentement
J'accepte de participer à la recherche *Revitaliser les châtaigneraies en Corse: découvrir le savoir-faire des castanéiculteurs pour développer une compréhension approfondie des possibilités pour relancer u castagnetu*.
Ma signature atteste de mon consentement à participer à cette étude. Je comprends que je suis libre de me retirer à tout moment de l'étude sans aucune conséquence pour moi.

Signatures

Signature du participant	Signature du chercheur

Lieu et date :

Pour tout renseignement supplémentaire concernant vos droits, vous pouvez vous adresser à :

Niek Pepels, responsable de cette étude
Etudiant de l'ISARA (Institut Supérieur d'Agriculture Rhône-Alpes) et de l'Université de Wageningen aux Pays-Bas

p.niek@live.nl (adresse e-mail privé)
npepels@etu.isara.fr ou niek.pepels@wur.nl (deux adresses e-mails professionnelles valides jusqu'en Septembre 2020)

Numéro téléphone : 0031682160047

Appendix F

Deductive coding sheet

The deductive coding sheet based on the questionnaire (**Appendix D**) is shown below.

	A	B	C	D	E	F	G	H	I	J
5			Answers from each participant			Answers from each participant			Answers from each particip	
6	Research question	1		Research question	2		Reseach question	3		
7	GALL WASP	Influence cynips châtaigneraie		RESTORING ORCHAR	Site selection conditions for reg. orchard		NEED TO DIVERSIF	Viability of monoactivity (chestnuts)		
8		Work prof. institutions			Time required to reach good productivity			How to facilitate the process of diversification		
9		Endemic resistant varieties			Financial aspects restoration		STRATEGIES OF DI'	Diversification of your orchard		
10		Resistant hybrid variety		LAND TRANSMISSIO	Why problem?			Other diversification activities outside orchard implemented		
11		Future development			How to facilitate it?			Diversification strategies you heard of done by others		
12	INK DISEASE	Past influence of ink disease on chestnut orchard			Helpful conditions for a successful restoration			Acceptation des habitants locaux d'une diversification		
13		Risk perception		RELEVANT SOCIAL PI	Cooperatives			Diversification strategies considered		
14		Control methods			Mentality of the youth			Ideas of diversification chestnut orchard		
15		Influence location			Civil society involvement			Honey		
16		Resistant varieties			Politicial/governmental changes		SHIITAKE	Adaptibility to local markets		
17		Methods to improve soil quality			Social living conditions complicating restoration			Compatibility with chestnut activities		
18	BLIGHT	Past influence blight on orchards			Social-economic dynamics over time			Adaptability to ecological conditions		
19		Risk perception						Economic viability		
20		Control methods performed						Tips		
21		Dead wood management					HAZELNUT	Adaptibility to local markets		
22	CLIMATE CHANGE	Observations						Compatibility with chestnut activities		
23		Impact position of orchard						Adaptability to ecological conditions		
24		Water retention structures						Economic viability		
25		Irrigation						Tips		
26		Other water-retaining measures								
27		Resistant varieties								
28		Wildfires								
29	VARIETIES	Planting hybrids								
30	LIVESTOCK	Observation of damage								
31		Solutions								
32		Historical situation								
33	KNOW-HOW	Change in methods current and previous generation								
34	FINANCIAL AID	Financial support program gall wasp damage								
35	FUTURE VISIONS	Chestnut orchards in 10 years								
36		Chestnut sector in 10 years								
37	CHESTNUT TREE	Productivity								
38		Production								
39		Understory/soil								

Appendix G

Biological control of the chestnut gall wasp

<u>Classical biological control with *Torymus sinensis*</u>

Several natural enemies occur in the chestnut gall wasps' native range in China. The most investigated one is *Torymus sinensis*, a Chinese torymid that parasitises the chestnut gall wasp. *T. sinensis* adults lay eggs in the same buds as the chestnut gall wasps do, and their larvae will kill the larvae of the chestnut gall wasp (Cho and Lee, 1963). In Japan, where the introduction of the chestnut gall wasp caused major problems to the Japanese chestnut production a while ago, it was found that classical biological control (the mass rearing, release, and permanent settlement of the reared control agent in order to control an exotic pest (Howarth, 1991)) with *T. sinensis* worked very well (Moriya, Shiga & Adachi, 2003). After the initial spread of *T. sinensis*, its populations increased exponentially, and it became the most abundant and successful parasitoid of the chestnut gall wasp in Japan (Aebi *et al.*, 2006), successfully controlling chestnut gall wasp to below the tolerable injury threshold value (30% damage) (Avtzis *et al.*, 2019).
This experience provided hope for the European context.

The first European *T. sinensis* releases were in Italy in 2005 (Quacchia *et al.*, 2008) and it took around nine years to observe a significantly reduced damage caused by the chestnut gall wasp (Ferracini *et al.*, 2019). Populations of *T. sinensis* increased quickly after introduction in Italy (Borowiec *et al.*, 2018) indicating a successful adaptation to the local ecosystem. In other European regions, this method of biological control seems to work as well. Measures in European orchards (including several Corsican orchards) showed a steady increase of the population of *T. sinensis* in the first five years after release, a high infestation rate (90% of the galls were infested) and a subsequent decline in the chestnut gall wasp population (Muru *et al.*, 2019).

In general, it seems that the use of *T. sinensis* in Europe is very effective, resulting in high parasitism rates of the chestnut gall wasp, a quick spread and the establishment of healthy, genetically diverse populations (Matošević *et al.*, 2017). In northern Italy, the earliest European country to release *T. sinensis* (Quacchia *et al.*, 2008), nine years after the initial release of *T. sinensis*, chestnut gall wasp infestation of chestnut trees was reduced to almost zero (Ferracini *et al.*, 2019). In France as well, analyses of the different introductions show an exponential increase in the population of *T. sinensis* in the first years after introduction, followed by a decrease in chestnut gall wasp infestations (Borowiec *et al.*, 2018). Interestingly, the number of individuals released did not matter; even the release of a small number of individuals was highly effective, in part because of the high parasitism rate (Borowiec *et al.*, 2018). In orchards that were characterised by effective control of the chestnut gall wasp by *T. sinensis*, *T. sinensis* populations have plummeted to low numbers, suggesting a newly established equilibrium between *T. sinensis* and the chestnut gall wasp that reduces the chestnut gall wasp's damage to an acceptable low level (Borowiec *et al.*, 2018). Despite these positive results, the major challenge is the required time to reach this new equilibrium where the damage level caused by the chestnut gall wasp is low (at least seven years) (Borowiec *et al.*, 2018; Ferracini *et al.*, 2019).

Several native European parasitoids are also able to parasitise the chestnut gall wasp, but it turns out that only a certain fraction is controlled due to low (or no) adaptation of the local parasitoids to this exotic pest insect (Muru *et al.*, 2019). In Italy, as many as 27 species of native parasitoids have been found to parasitise the chestnut gall wasp (Quacchia *et al.*, 2013) but most native species are not effective, having parasitism rates as low as 3%. However, in Italy, several years after the arrival of the chestnut gall wasp, up to 32% of the chestnut gall wasp galls were parasitised by native parasitoids (Santi and Maini, 2011). It is believed that over time, if the local parasitoids have had the chance to adapt to the chestnut gall wasp, the process of parasitising the chestnut gall wasp becomes more effective (Santi and Maini, 2011). In Italy for example, it was found that *Torymus flavipes* (a native *Torymus* parasitoid) showed a rapid behavioural adaptation to the suddenly available chestnut gall wasp and was responsible for a major part of the colonised galls found in the study (Santi and Maini, 2011). This suggests that native parasitoid species might indeed adapt to the chestnut gall wasp and, over time, reduce its damage.

Narrowing down to Corsica, an endemic parasitoid has been found to use the chestnut gall wasp as a host; the population of *Mesopolobus sericeus* has strongly increased in response to the arrival of the chestnut gall wasp, and it appears that *M. sericeus* can coexist alongside *T. sinensis* while preying on the chestnut gall wasp (Muru *et al.*, 2019). In Tuscany as well, *M. sericeus* has been observed parasitising the chestnut gall wasp (Panzavolta *et al.*, 2013) and it has been suggested that the presence of oak species in or around Corsican castagnetu might enhance the populations of *M. sericeus* and facilitate its introduction to castagnetu where it switches to the chestnut gall wasp (Muru *et al.*, 2019).

Because of the successful implementation of *T. sinensis* as a classical biological control agent in other regions and the uncertainty regarding the efficacy of native parasitoid species, *T. sinensis* was also mass-released in Corsica, starting in 2011 (AOCfarinedechâtaignecorse, 2018). In 2018, *T. sinensis* was present on every studied site in Corsica, indicating a good spread (AOCfarinedechâtaignecorse, 2018). In the period 2011-2017, there have been 1 613 mass releases (100 female *T. sinensis* individuals per release) distributed over Corsica, and their populations have increased exponentially after release, indicating a good local adaptation similar to the Italian situation described earlier (AOCfarinedechâtaignecorse, 2018; Borowiec *et al.*, 2018). Still, despite the abundance of *T. sinensis*, a significant decrease in the damage caused by the chestnut gall wasp was not been, as indicated by the low chestnut yields in the last years, until recently (DRAAF Corse, 2015, 2018).

In 2019, for the first time after the arrival of the chestnut gall wasp, many chestnut farmers reported the first increased chestnut yields since the arrival of the chestnut gall wasp. Like what has been observed in Italy, it took several years before the trees started to look significantly healthier and production levels started to rise again.

It is hoped and expected that the damage caused by the chestnut gall wasp will decrease rapidly in the coming years, similar to what has been observed in other European regions such as parts of Italy and continental France where this classical biocontrol has proved to be highly effective from around seven to nine years after the first introduction onwards (Borowiec *et al.*, 2018; Bucchini, 2013; DRAAF Corse, 2017; Ferracini *et al.*, 2019).

Several concerns about hybridisation with other endemic *Torymus* species and concerns about population declines of other potential target species (native gall wasps) with the implementation of *T. sinensis* in Europe have been raised (Gibbs *et al.*, 2011). Even though T. sinensis is considered monophagous in its native range, it has been found to be able to parasitise a native gall wasp "*Biorhiza pallida*" in Italy (Ferracini *et al.*, 2015).

Continuous monitoring of *T. sinensis* populations, chestnut gall wasp populations and gall infestation by native species need to be done in the coming years to ensure successful and ecologically responsible control of the chestnut gall wasp population.

Appendix H

Bigger chestnut leaves due to *T. sinensis*

Fig. 1 shows the author's observations that many, though definitely not all chestnut trees in the Orezza valley (the heart of the former chestnut civilisation in Castagniccia), are looking better. Leaves are getting bigger, indicating that *T. sinensis* is starting to be effective.

Figure 1. The results of the biological control of the chestnut gall wasp: many chestnuts in Corsica make big leaves again. Photo taken in Orezza valley.

Appendix I

Solutions to control blight

Biological control through inoculation of hypovirulent fungus in diseased orchards
Biological control is an effective method that can change the chestnut blight from being virulent and destructive, to being hypovirulent and well-tolerated by the chestnut trees. It is especially useful to implement in regions where the CHV1 virus does not occur.

Biological control works as following: virus-infected strains of *E. parasitica* are cultivated by companies. Chestnut producers can buy isolates and inoculate infected trees in their orchard. Consequently, the hypovirulent inoculum will contaminate the virus-free fungus (that causes the diseased trees), making it hypovirulent. It takes approximately ten years from the moment of the first inoculations onwards, until the whole orchard is expected to be disease-free and already in the first three years, as much as 50% of the cankers can be healed (Robin *et al.*, 2010). This is thanks to the spread of hypovirulent spores from the inoculated trees to other trees.

A complicating factor is the vegetative compatibility of the fungus (vc type); because the virus is cytoplasmic, it is only present in the mycelium and the conidia but not the ascospores (Robin *et al.*, 2010). This means that there are two ways to contaminate the harmful *E. parasitica* strains with the virus: via asexual reproduction (conidia) or vegetative spread between the non-virulent and virulent fungi. Via conidia, the hypoviral strain can increase in frequency in the *E. parasitica population* (Robin *et al.*, 2010).
Biological control, however, mainly relies on the latter: vegetative spread between two compatible isolates (meaning the two isolates have the same vc type) (Trestic *et al.*, 2001).
There are two popular methods to inoculate the hypovirulent fungus isolates in the orchard.

The first is called in French *"Méthode à l'emporte-pièce".* This method consists of drilling holes around the canker. In these holes, a gel with the hypovirulent strain(s) is placed, after which they will spread inwards and (if compatible with the virulent strain) merge, hence spreading the virus to the harmful strain (Chataignier-conservatoire, n.d.). This horizontal transmission relies on the hyphal anastomosis (merging), meaning that the inoculated virus-containing strain merges with the virus-free strain, thereby transmitting the virus cytoplasmically (Meyer *et al.*, 2019).
Six different vc types were observed in Corsica, with EU-2 forming 60% of the total, suggesting that biological control can be quite easily accomplished. In the French region Dordogne, 14 different vc types occur, making biological control more complicated than in Corsica (Brusini, 2009; Robin *et al.*, 2000). Furthermore, in Corsica, only four types were shown to be the dominant ones, from which EU-2 made up a large part (Brusini, 2009).

The second method is called *"Méthode par greffage"* which entails making one long scratch instead of several holes; right across the canker spot, the bark is lifted by making a long scratch with a knife. Then, a gel containing the hypovirulent strain is added, and the same process starts as for the first method (Chataignier-conservatoire, n.d.).

Sanitary practices to limit the development of the blight
Sanitary practices are an important part to prevent contamination of trees.
The wise treatment of dead wood is critical from this point of view. *E. parasitica* has been shown to survive for more than a year on dead chestnut branches (Prospero *et al.*, 2006) and experiments have shown that the hypoviral strain is able to spread virus-containing conidia, but not ascospores, more than one year after the death of the branch (Prospero *et al.*, 2006).

Former recommendations were to remove all fresh dead chestnut wood from the castagnetu because of the capacity of *E. parasitica* to reproduce asexually on this wood. However, a recent study found that fresh dead chestnut wood colonised by *E. parasitica* infected by the CHV1 virus can actually be a useful tool to increase virus-transmission and reduce *E. parasitica* problems in castagnetu (Meyer *et al.*, 2019). It suggests that in regions where CHV1 occurs naturally, stocking trimmed branches in a castagnetu can actually contribute to an accelerated immunity of the whole orchard (Meyer *et al.*, 2019).

Therefore, the use of dead wood piled up in castagnetu can, in case of the presence of the virus-infected *E. parasitica* on the dead wood, represent an important strategy to speed up the process of virus dispersal throughout the entire castagnetu (Prospero *et al.*, 2006). However, if there is no sign of the CHV1 virus in the region (or in the orchard), then stocking dead wood would likely worsen the problem because it would enable the virulent *E. parasitica* fungus (if the wood is contaminated) to spread its spores (Meyer *et al.,* 2019). In Corsica, where the proportion of virus-infected *E. parasitica* was only 10% of the total *E. parasitica* population in 2000 (more recent data could not be found in scientific literature but this number has likely gone up as lots of treatment has been done in the following years, as confirmed by Camille, Corsica's chestnut expert working for the chestnut sector), a potential solution to the problem could be to infect fresh dead wood with the viral strain, pile the wood up in a diseased castagnetu and in this way increase the healing process of the infected trees.

Cultivar selection
Hybrids like *Bouche de Bétizac* or *Marigoule* have been developed to overcome ink disease. Certain varieties like the two mentioned here also show increased resistance to blight, although there is no fully resistant hybrid yet (Hennion, 2009; L'institut de l'agriculture et de l'alimentation biologiques, 2001). Again, the use of hybrids is not what the Corsican chestnut sector has chosen to do.

Chemical control
Only limited data is available for chemical control of chestnut blight, mainly because most chestnut farmers are AOC-certified, which does not allow chemical control.

Preventative measures
Grafting poses a high risk of infection by *E. parasitica.* It is essential that grafting material is free from the fungus and that the material is adequately cleaned with disinfecting material to prevent the introduction of the disease to trees (Rigling *et al.*, 2014).
Buying pre-grafted seedlings should be done from controlled nurseries to ensure disease-free material.

Appendix J

Feral animals

Background and problem description

When the European milk quota was introduced in 1984 (Eurostat, 2018), many Corsican farmers switched from producing milk to producing meat. This meat production was subsidised by the Common Agricultural Policy (CAP). Consequently, many farmers took more animals than their land could support; they let the animals roam freely in the countryside and reported fewer animals than they owned. In the early 90s, Brussels discovered this fraud and subsequently suspended the subsidies, which made many farmers abandon their cows and pigs (Delanglade and Lhaik, 1996).

Besides problems related to abandoned livestock, problems caused by the animals of *current* livestock farmers in rural regions, who let the animals roam semi-freely, impact the castagnetu as well. This practice started in the second half of the last century, and the reason why livestock farmers could get away with this practice was the abandonment of the countryside itself. The large-scale depopulation served as an incentive for the livestock farmers to let their animals roam semi-freely. Because of the large-scale depopulation of most rural regions, most castagnetu were already abandoned, so the livestock farmers faced little resistance from other inhabitants. Furthermore, livestock farmers were often one of the only permanent inhabitants of a village, so they often have disproportionate power within the community as the municipality does not want to create conflicts with the rare permanent inhabitants.

The feral animals have a deleterious effect on the castagnetu, especially the pigs and cows. Firstly, pigs are problematic because they turn the soil, resulting in erosion and accelerated soil organic matter breakdown which puts the castagnetu at a higher risk for droughts. Secondly, as mentioned earlier, many participants thought that this soil disturbance is an essential contributor to the increased incidence of ink disease.

Besides pigs, cows complicate the revival of abandoned castagnetu as well. They eat the young chestnut seedlings resulting in a complete absence of young chestnuts in certain areas. This lack of regeneration is particularly worrying regarding the future, when lots of old chestnuts will have died and no young chestnuts will be present to take over their place.

Solutions

Protection of the orchards against the feral animals by keeping them out.

The first solution can be implemented by fencing the orchards, which is according to the farmers, one of the first most essential steps of the restoration process of an abandoned castagnetu. This method is effective, but is expensive and does not address the root cause of the problem, which is the overpopulation of the feral animals.

Controlling the populations of the feral animals.

The second solution seeks to address this root cause by reducing the populations of the animals. Because Corsica has never been home to large carnivores such as wolves, bears or lynxes, rewilding Corsica (meaning introducing large carnivores from abroad) is not an ecologically responsible option as it would drastically influence Corsica's endemic fauna. Therefore, the Corsicans themselves are the only ones able to control the populations. Currently, recreational hunting is a popular activity in Corsica but it fails to reduce the populations of the feral animals below a critical injury level due to the size of the populations, the high reproductive capacity of especially the pigs, and the challenging mountainous terrain which provides animals with many hiding places.

An option would be to create an environmentally oriented export market, like has been done in Australia to control feral animals introduced by the Europeans which endanger endemic flora and fauna. With the revenue from the export of feral animal meat, a long-lasting effective control of the populations can be safeguarded (Smith, 2019). Regarding the increased interest in recent years in pasture-raised or wild animal meat, this option has quite some potential, but is not implemented yet in Corsica.

Appendix K

Ink disease

Chestnut ink disease is a root disease that is caused by several species of *Phytophthora* oomycetes. In Europe, the two most aggressive oomycete species are *Phytophthora cambivora* and *Phytophthora cinnamomi* (Vannini and Vettraino, 2001). Other species have been found in diseased castagnetu, but their role is not clear yet, and they are less important than the two species mentioned above (Vannini and Vettraino, 2001). Chestnut ink disease is present in Europe since the 18th or 19th century (Vannini and Vettraino, 2001) and has caused a substantial decline in productivity of chestnut trees in all European countries where chestnuts are cultivated (Černý *et al.*, 2008; Vannini and Vettraino, 2001).

The disease affects the main roots of the sweet chestnut tree and causes root and collar rot (Černý *et al.*, 2008; Vannini and Vettraino, 2001). Symptoms include thinning of the crown, reduced leaf size and immature husks that remain attached to the branches of the tree in winter. Upon infection, the roots produce black exudates that stain the surrounding soil (hence the name "ink disease") (Vannini and Vettraino, 2001). It is able to kill mature trees and is a serious threat for the chestnut trees (Černý *et al.*, 2008; Vannini and Vettraino, 2001).

In Corsica, the disease has manifested itself for the first time around 1880 (Perry, 1984). The severity and the spread of the disease are linked to several climatological and geographical factors such as the proximity of roads and water channelling structures, precipitation, slope orientation, soil compaction, fertilisation practices and homogeneity of the stands.

1 Proximity to roads and water channelling structures

The proximity to roads and water channelling structures such as creeks has been shown to positively impact disease severity and frequency (Vannini *et al.*, 2010). As ink disease is caused by oomycetes, water is one of the most important vectors for dispersal of spores (Giblin, 2015). It has been noted that downhill of roads, creeks and natural drainage sites, a high incidence of the disease occurs due to the gravitational movement of water (with dissolved spores) (Vannini *et al.*, 2010). Also, close to (not only downhill of) natural drainage sites such as creeks, more disease occurs because flooding (hence, infection with the dissolved spores) infects surrounding chestnut trees (Vannini *et al.*, 2010).

2 Rainfall

In areas with high rainfall (>1000 mm per year) and limited summer drought, chestnuts have an increased chance of being affected by ink disease which can be explained by the fact that the oomycetes thrive in more humid conditions (Vettraino *et al.*, 2005).

3 Slope orientation

As slope orientation strongly influences the soil conditions (humidity) and the oomycetes depend on water-rich conditions, it could be hypothesised that north-oriented slopes, which tend to be wetter and more humid, would suffer most from ink disease. In Portugal, however, it was found that chestnut stands on south-facing slopes experienced most ink disease (Vannini and Vettraino, 2001). Conditions here were characterised by low air humidity, dry soil, high air temperature and high wind speeds. The authors concluded that these conditions were more stressful to the trees (than humid conditions) and, hence, made the trees more vulnerable to the disease. This is paradoxical because these conditions do not seem optimal for water-loving oomycetes (Vannini and Vettraino, 2001). Probably, both north and south oriented castagnetu can be particularly vulnerable to the disease depending on the region. In regions without too much precipitation, north-facing castagnetu might not experience very wet conditions (especially on very steep slopes where roots reach the air) but might benefit from the reduced stress (due to the higher moisture availability which normally is beneficial for plant growth). Consequently, they might be less vulnerable to the disease than castagnetu on south-oriented slopes with long and stressful summer droughts. In summary, slope orientation is a research topic that deserves more attention. At this moment, results are ambivalent.

4 Soil compaction

Human activities that compact the soil (heavy machinery use in plantations) increase the risk for *Phytophthora* infestations, presumably by increasing the risk for waterlogged conditions, by reducing the populations of 'healthy' aerobic microorganisms and by restricting root growth (Fonseca *et al.*, 2004; Martins *et al.*, 2007). A study found that for each extra unit of compaction, odds of having the disease increased ten-fold (Fonseca *et al.*, 2004), suggesting that preventing compaction is an important method to prevent ink disease.

5 Fertilisation practices

The role of fertilisation via manuring is under discussion. On the one hand, it has been suggested that because of the saprotrophic nature of the ink disease-causing oomycetes, manuring can stimulate its development (Fonseca *et al.*, 2004). On the other hand, manuring can lead to increased aeration and reduced water-logging, hence reducing the optimal conditions for ink disease to exist (Fonseca *et al.*, 2004).

6 Homogeneity of stands

One of the major problems of traditional castagnetu is the homogeneity of the system; the canopy layer is a monoculture of chestnut trees, so the ink disease can spread relatively quickly throughout the castagnetu. Root-root contact with nearby chestnut trees is an important dispersal mechanism for the oomycetes, and therefore, the traditional castagnetu are prone to a rapid spread from tree to tree (Martins *et al.*, 2007).

Even though the *Phytophthora* oomycetes have been present in Corsica for more than a century, it is only in the last decades that an increased incidence of ink disease occurred across Corsica. The high density of pigs was particularly often blamed for the increased incidence of the disease. The abandoned castagnetu are particularly at high risk because pigs have free access to those castagnetu (while most (but not all) managed castagnetu are fenced). Many participants believed that the pigs are an essential cause of the increased ink disease incidence for two reasons:

1. They can spread the spores of the fungus throughout Corsica, like wild animals such as hare can do (Delanglade and Lhaik, 1996; Rigling *et al.*, 2014; Russin *et al.*, 1984).
2. The disturbance of the soil impacts the mycorrhizal community that (if not disturbed) can have a protective effect against the infection by the *Phytophthora* oomycetes as the fungal mantle can function as a protective barrier around the roots of the chestnuts (Aryantha *et al.*, 2000; Branzanti *et al.*, 1999; Choupina *et al.*, 2014), explained in detail later in this appendix).

Solutions

Several methods can be used to control the disease in chestnut trees.

Gandolfo method

This method has been used in Italy to get rid of the oomycetes that affect the principal roots of the chestnut trees (Vannini and Vettraino, 2001). It consists of removing all the soil that surrounds the roots and is grounded on the fact that chestnut trees on very steep sites do not succumb to the malady because their roots reach the air (Perry, 1984). It is a very labour-intensive method though, and it is unlikely that chestnut farmers are willing to dig out their tree's roots, especially if they own hundreds of chestnut trees.

Breeding resistant varieties

Castanea sativa (European chestnut) is very vulnerable to ink disease. Even though there are hundreds of *Castanea sativa* varieties in Europe, all of them are vulnerable to the disease. On the other hand, Asian species such as *Castanea mollissima* (Chinese chestnut) and *Castanea crenata* (Japanese chestnut) are much more resistant to the disease (Vannini and Vettraino, 2001). The problem with them is that they perform poorly under European climatic conditions, so attempts have been made to create *C. sativa x C. crenata* hybrids to develop chestnuts better adapted to the European climatic conditions while maintaining the resistance of the Japanese chestnuts. Several hybrids such as "*Marigoule*", "*Ferosacre"'*, "*Marlhac"*, "*Marsol"* and "*Maraval"* have been developed for this purpose and they can serve either as a rootstock for the culturally important *C. sativa* varieties, or can be cultivated on their own (so without grafting) (Vannini and Vettraino, 2001). As mentioned earlier, hybrids are not chosen by the Corsican chestnut sector, so this solution does not apply to the Corsican context.

Biological control

Antagonistic microorganisms are effective in reducing the number of ink disease-causing oomycetes in the soil though the evidence is scarce (Aryantha *et al.*, 2000; Choupina *et al.*, 2014). Antagonistic microorganisms can be introduced to the soil with manure or compost additions.
Several types of composts and manures have been tested to gain a better understanding of their potential antagonistic function. On the one hand, they could be a source of pathogenic microorganisms, so worsen the disease when added to diseased chestnut trees. On the other hand, they could reduce the disease severity because of the possible beneficial microorganisms contained by the compost or manure (Aryantha *et al.*, 2000). One study found that only the addition of fresh or (five weeks) composted chicken manure was effective in reducing the survival of *Phytophthora* species (Aryantha *et al.*, 2000). The chicken manure and compost contains beneficial antagonistic microorganisms such as certain fungal species and fluorescent pseudomonads, and these microorganisms exerted a strong negative effect on the development of *P. cinnamomi* (Aryantha *et al.*, 2000). Cow, sheep and horse manure and compost did not show any significant suppressive effect.

Inoculation of chestnut seedlings with ectomycorrhizal fungi has also been shown to be effective in preventing ink disease (Branzanti *et al.,* 1999). It has been found that the ectomycorrhizal fungi "*Laccaria laccata", "Hebeloma crustiliniforme", "Hebeloma sinapizans"* and "*Paxillus involutus"* protect the roots of *C. sativa* seedlings from infection by both *P. cinnamomi* and *P. cambivora* (Branzanti *et al*., 1999). When young chestnut seedlings (seven months old) were inoculated with these four species of ectomycorrhizal fungi and with a *Phytophthora* fungus (while a control group was not inoculated with mycorrhizal fungi), the inoculated seedlings did not show any sign of pathogen infection (Branzanti *et al*., 1999). Inoculated mycorrhizal plants had a better root and shoot development than the control group. The mechanism of protection was the fungal mantle that functioned as a mechanical barrier against *Phytophthora* infection; chestnut roots with a complete fungal mantle showed no infection by neither of the two *Phytophthora* species, while non-mycorrhizal roots of the control seedlings were heavily infected by the pathogens (Branzanti *et al.*, 1999).
This suggests that certain species of ectomycorrhizal species are promising candidates to increase the resistance of the *Phytophthora*-sensitive European chestnut. However, it is questionable how these results should be interpreted in existing castagnetu; both healthy and diseased castagnetu have been found to contain more than 50 species of mycorrhizal fungi (Diamandis and Perlerou, 2001). Therefore, not all ectomycorrhizal fungi are protective against ink disease. In a study that

compared a diseased Italian castagnetu and a healthy Italian castagnetu, important differences in the relative abundance of ectomycorrhizal species between the ectomycorrhizal communities have been observed (Blom *et al.*, 2009).
However, due to the large diversity and overlap in species between the diseased and healthy stand, it is hard to find out which species are protective. It can be concluded that there is a clear protective role for certain species of ectomycorrhizal fungi against ink disease in *C. sativa*, but more research needs to be carried out to find out which species are most promising and whether this can be made into a product (for example an inoculum of certain species) that can be applied to the soil in a diseased stand of chestnuts.

Chemical control

One of the most effective products to treat diseased trees is potassium phosphite (Gentile *et al.*, 2009). This molecule functions as a fungicide in two distinct manners: it is directly toxic to the *Phytophthora* fungi responsible for ink disease, and it is believed to boost the chestnut's own natural defence system (Maso *et al.*, 2017). It can be applied with foliar sprays (in small nursery chestnut seedlings) or with xylem injections (in mature chestnuts). Experiments in diseased mature chestnut trees have shown that annual xylem injections can be very effective to reduce disease symptoms but the effectiveness is dependent on the severity of the disease (Gentile *et al.*, 2009). In the most severely diseased trees, xylem application shows no satisfactory results, but in intermediate and lightly diseased trees, it resulted in a marked improvement of the trees' condition, vigour and productivity very quickly after application (Gentile *et al.,* 2009). One of the benefits of the xylem application of this pesticide is that the environmental risks are small (no contamination of other plants in the orchard) (Gentile *et al.,* 2009).

Increase castagnetu's soil quality by reducing compaction

As mentioned earlier, soil compaction can lead to waterlogged conditions at certain times of the year, which stimulates the dispersal of spores of the *Phytophthora* oomycetes (Giblin, 2015). Also, compacted soil conditions can stimulate the development of populations of harmful microorganisms (such as the *Phytophthora* species) and decrease the populations of beneficial antagonistic microorganisms (Fonseca *et al.*, 2004; Martins *et al.*, 2007).
Besides the problems mentioned above associated with compaction, it also puts additional stress on the trees by lowering summer water availability and, hence, by creating conditions not unlike south-facing slopes which have been found to worsen ink disease outcomes in castagnetu (Dal Maso and Montecchio, 2015).

Possible ways to improve soil quality is to add manure (preferably chicken manure or compost) and mulch (Aryantha *et al.*, 2000). In avocado cultivation, where *P. cinnamomi* can cause similar problems as in chestnut cultivation, the addition of mulches can strongly reduce the *P. cinnamomi* infections of the trees (Giblin, 2015). Interestingly, wild avocados growing in aerated, uncompacted rainforest soil are quasi-resistant to ink disease, while cultivated avocados growing in compacted soils are vulnerable (Broadbent and Baker, 1974). The improvement of soil quality by adding mulches and stimulating beneficial microorganisms is very effective in preventing ink disease outbreaks in avocado orchards (Giblin, 2015). The main difference between diseased and healthy orchards is the soil organic matter level of the soil and the biological activity and complexity of the topsoil (Giblin, 2015). *P. cinnamomi* seems to be strongly affected by rich soil biodiversity consisting of antagonistic species that thrive in soil organic matter rich conditions. These results suggest that *P. cinnamom*i might be controlled in castagnetu by increasing soil organic matter levels and abundance of beneficial microorganisms, hence by improving overall soil quality (Giblin, 2015), but specific research focused on Corsican castagnetu (and not on avocados) is strongly needed.

Strikingly, most participants were not aware of any effective control method of this disease. Only Olivier, a large-scale chestnut farmer in Castagniccia, mentioned the use of antagonistic microorganisms to fight the disease.

Though most farmers did not implement any control methods, the agricultural institutions (such as the *Chambre* and the *Groupement* are considering or are already testing in pilot studies several of the possible solutions such as green manures (to improve the soil quality and mycelium community). For example, Léa, Corsica's chestnut expert working for the chestnut sector, mentioned the plans to investigate the effect of different green manures on the soil quality in the castagnetu and the possible effects on water requirements and ink disease developments.

Besides green manures, Léa mentioned that the chestnut sector is considering the use of endemic ink-disease resistant rootstocks. The idea is to find individual Corsican endemic trees that do not suffer from ink disease while nearby trees are being felled by it. This phenomenon could be explained by genetic differences, and certain individual trees might be, for some unknown reason, resistant to the disease. After having identified resistant individuals, these individual trees could be propagated (technically speaking propagate only the rootstock) and these rootstocks can then be used for endemic Corsican varieties. The great benefit of this method is having a locally-adapted Corsican rootstock instead of a hybrid which is not adapted to Corsica's local conditions.

Appendix L

Climate change

Background and problem description

In the last three decades, several severe droughts have strongly influenced the production of chestnuts. Consequently, many chestnut trees lost their leaves in August and thousands of chestnut trees died, according to Fabien, the large-scale chestnut farmer mentioned above.

The chestnut tree needs summer rain, especially around the mid or end of August to be able to make sufficiently large chestnuts. The reason why the microregion of Castagniccia has been such a favourable place to cultivate chestnuts is its climate. It is not characterised by a typical Mediterranean climate, meaning that even in July and August, rain events usually occur. However, since around 30 years ago, multiple participants observed that these critical August rains have become more sporadic (not only in Castagniccia but in other mountainous chestnut-growing regions in Corsica as well), posing a serious problem on the non-irrigated chestnut culture of Corsica (and AOC producers are not allowed to have permanent irrigation, as indicated by Gabriel, mentioned above).

Also, periods of intense summer heat have become more frequent in the last decades, which is thought to put additional stress on the trees. Climatic change is believed to seriously threaten the tree's future survival and productivity, especially at a low altitude where it is warmer and where precipitation is less than at higher altitudes (Rome and Giorgetti, 2007).

Solutions

To adapt the orchards to a changing climate, the chestnut sector is currently researching several options.

Firstly, different green manures are being investigated to increase soil organic matter levels and consequently, the soil's water-holding capacity. Results will appear in the coming years.

Secondly, the sector has placed sensors that measure the soil's humidity in the castagnetu of Gabriel, which is situated in the dry Niolo region. These sensors will provide detailed data indicated when and which parcels require irrigation. As permanent irrigation of AOC castagnetu is not authorised, understanding when and where to use temporary irrigation is essential.

Lastly, finding endemic varieties that better resist a drier climate is another solution that the chestnut sector is implementing.

Appendix M

The stepwise process of the restoration approach

Here, based on the expertise of the study's participants, the stepwise method to restore degraded castagnetu is described.

1 Selection of the land

The first step is to find a castagnetu that is not too degraded and fulfils several basic conditions in order to make restoration possible. The first thing to do when comparing different castagnetu for their potential for restoration is to evaluate the position of the castagnetu in the landscape in the scope of climate change (so taking into consideration the effect of altitude, slope orientation, presence of water). Then, the health of the trees and the potential to bring them back into production should be assessed by experts from the *Chambre*. Because of the advanced age of many trees, and the years of stress caused by the diseases and abandonment, many chestnut trees are at the edge of their lifespan and are at high risk of collapse. Therefore, it is key for a successful long-term restoration to find a castagnetu with trees that still have enough future potential.

Another essential factor to keep in mind while looking for land is the availability of infrastructure. Often, orchards are not adjacent to the few roads that cross most of the chestnut-growing regions in Corsica. Having a basic infrastructure nearby or even in the castagnetu is very helpful. Furthermore, if possible, mechanisation should be kept in mind. Many participants such as Anna, a small-scale chestnut farmer who has almost all the machines to process her chestnuts herself into flour, said that they believed that the chestnut culture would only be compatible with modern life if mechanisation is possible.

If diversification of the castagnetu is considered, it should be planned before starting the process of restoration. It is crucial to figure out the needs of the other activity; for example, if a farmer wants to diversify with hazelnuts, he/she should consider the planting of hazelnuts into consideration when restoring the castagnetu so that he/she knows which trees should be felled to allow sufficient sunlight for the hazelnuts. Lastly, as described earlier, water is a crucial resource for the successful restoration of a degraded castagnetu. If water-infrastructure (small dams, swales, terraces) is considered to be made, it is wise to choose land with a gentle slope (as far as possible in Corsica) over very steep land to facilitate the construction of such infrastructure. It is imperative to make a design of the desired water infrastructure because this infrastructure should be created as one of the first steps in the process as it entails, in most cases, a permanent change to the land (Shepard, 2013).

2 Clearing the understory

The next step is to clear the understory and the undesired tree species that invaded the abandoned castagnetu. This is a challenging job because often, most abandoned castagnetu are overgrown by brambles which makes access to the orchard practically impossible. Besides brambles, other tree species (holm oak, alder trees, cherry trees) need to be removed. Furthermore, old unstable chestnut trees should be removed as well.

As suggested by Benjamin, the young Corsican farmer with lots of experience with agroecological farming, the wood that is cut after clearing the orchard can be used to stabilise the soil on steep land and to prevent erosion by strategically placing the wood on places where water tends to accumulate and flow downwards during heavy rain. Also, it is suggested by the earlier mentioned study's participant Charles, who is specialised in self- sufficient living, to make fence posts from the cut wood to save much money (by making fence posts yourself instead of buying).

3 Fencing the land

Because of the disturbing effect of the (abandoned) pigs that turn the soil and make the soil bare and prone to erosion, and because some of these animals, in particularly goats, tend to eat almost anything, it is important to fence the castagnetu as soon as possible.

4 Pruning the chestnut trees and removing the suckers

Pruning is essential to recreate a productive crown and to remove diseased or dead branches (often caused by blight disease). Pruning is considered a dangerous job and is generally done by specially trained people from pruning companies. The costs to pay these pruners are high: around €200 to €300 per tree according to Camille, the local chestnut expert working for the Corsican chestnut sector. To prune one hectare of abandoned castagnetu would cost easily more than €7 000. However, the ODARC (a Corsican organisation for agricultural and rural development) finances part of the costs if the person is a "young farmer". Furthermore, some participants mentioned that several large-scale pruning companies are doing more harm than good when they are hired to prune the trees. Some do it too quick (by pruning too rigorously which is not tolerated by chestnuts), and this results in a lack of production for several years to come. Gabriel, a chestnut farmer and professional pruner noted that if the trees are pruned correctly (lightly), already in the year of or the year after the pruning, production can be expected. Therefore, one should get well informed about the different pruning companies to choose the right one. Besides pruning the branches, the suckers that come out of the base of many chestnut trees should be removed. These suckers (as the name suggests) suck up the energy, in other words, the tree invests in the growth of these branches rather than in the production of chestnuts.

5 Grafting the chestnuts

After years of abandonment, it is not always known which variety is grafted on which tree. Even if the variety is known, it could be useful to graft a known variety with a specific trait. Therefore, it is recommended to, if necessary, graft Corsican varieties that have a certain desired trait (such as a certain level of chestnut gall wasp tolerance (*Campanese*) or a high productivity) on the chestnut trees that must be restored.

6 General management

After step five, most of the restoration has been done. Now, the general management should start, which includes taking care of the trees (annual removal of dead/diseased branches, irrigation if necessary and treatment of cankers caused by blight disease). Besides taking care of the trees, taking care of the orchard's floor is also included here. Sowing green manures on the cleared orchard floor would help to control erosion and would make it harder for undesired woody species from entering the orchard again. Also, an herbaceous layer facilitates the process of harvesting the chestnuts as nets can easily be put on the herbaceous layer. Furthermore, as a diversification strategy, sheep could be raised.

7 Diversifying the castagnetu

As mentioned in the first restoration step, diversification should be considered well before the restoration of the orchard starts. Coming back to the example of hazelnuts, now that the orchard is restored and trees have been felled strategically to allow enough sunlight for the hazelnuts to thrive, the hazelnuts should be planted. If other diversification strategies are considered, they can be implemented as well from this moment onwards.

Appendix N

Diversification methods

Table 1 lists all the different diversification methods implemented by Corsica's chestnut farmers; both the agricultural as well as the non-agricultural activities are listed.

Table 1. All the diversification strategies listed by the participants as on the one hand being implemented by themselves or chestnut growers they know or on the other hand, being considered to become implemented.

Popularity	Agricultural diversification: animals	Agricultural diversification: plants or fungi	Non-agricultural diversification
Common	Sheep for meat	Olive trees	Site-visits and on-farm sales of value-added products
	Pigs for meat		
	Cattle for meat		
	Honeybees		
Occasional, rare or historically being done		Raspberries	Guesthouse
		Hazelnuts	
		Aromatic herbs (esp. Curry plant)	
		Strawberries	Mountain guide
		Saffron	Combination with academic job
		Classical fruit trees (apple, pear)	
		Maple (for syrup)	
		Vegetables	
		Walnut/Pecan	
Considered but not yet implemented	Chicken for both meat and eggs	Oyster and or shiitake cultivation	
		Figs	

		Cherries	

Hazelnuts
Most participants were positive about the possibilities to diversify the castagnetu with hazelnuts. Marketing opportunities were considered to be very good due to the strong demand for hazelnuts during the last years.
The ecological adaptability of hazelnuts to the local conditions faced in the castagnetu was also judged as reasonably good, although some participants questioned the possible cultivation at high altitude (meaning around 600-800 metres where most castagnetu can be found). From some participant's points of view, hazelnuts can only be grown at lower altitudes than chestnuts (up to 400 m). Hazelnuts are indeed usually only grown commercially in the eastern plains (close to the coast) up to around 400 metres of altitude.
In reality, though, hazelnuts do not prefer hot and dry conditions (found in the eastern plain) and prefer north-east orientations to avoid excessive evapotranspiration in summer (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2014). Most hazelnut groves at the coast in Corsica are only possible thanks to irrigation.

Furthermore, both the author and some farmers know examples of hazelnut groves in Corsica that do well at altitudes between 500 and 800 metres of altitude.

Figure 1. A small hazelnut grove created in a former castagnetu by Charles, the self-sufficient living expert living in Alesani valley mentioned above.

In **Fig. 1** for example, a very small hazelnut grove of is pictured at an altitude of around 800 metres on an east-oriented slope, planted in a former castagnetu. Individual plants produce around eleven kg of nuts annually, which is good productivity (Ritchie, 2008).
The compartmentalised thinking (hazelnuts are and should be grown at this altitude and chestnuts at this altitude) is one of the reasons that system diversification of the castagnetu is rarely implemented, even though the culture of hazelnuts is feasible at 600-800 metres of altitude.

Based on the presented design of the with hazelnuts diversified castagnetu, Charles, who has experience with growing hazelnuts in an abandoned castagnetu, cautioned for two important drawbacks of the original design (**Appendix B)**.

Firstly, hazelnuts need enough sunlight at an altitude typical for castagnetu (>600 m), so they can only be productive if grown in full light. In the original design, hazelnuts were planted too close to the chestnuts and, depending on the orientation of the land, several hazelnut bushes would be shaded too much by the trees to produce well. Depending on the orientation of the slope and the orientation of the whole valley (so case-specific), a design should be made that allows the hazelnuts to be at the sunniest side of the chestnuts which allows sufficient light interception by the hazelnuts.

Secondly, a diversification of an abandoned castagnetu with hazelnuts can only work if all the centuries old trees that are at risk of collapsing are cut before planting the hazelnuts. If not, and Charles has experienced this regularly, the old chestnut trees will damage or destroy the hazelnut bushes when storms (which are being observed increasingly regularly due to climate change in Corsica) uproot the ancient diseased chestnut trees. So, only if all the old chestnut trees that are at risk of being blown down by strong winds are cut before planting hazelnuts, such a diversification will work in the context of restoring an old castagnetu.

Shiitake

Most participants were surprised to find out about the diversification of castagnetu with shiitake mushrooms. Several reasons were given.
Firstly, in Corsican culture, like in French culture, collecting wild mushrooms in forests is a popular activity and the cultivation of mushrooms is not ingrained in Corsican culture.

Secondly, as far as the participants and the author could find out, there is presently not a single commercial shiitake producer on the island. All shiitake that is sold in Corsican stores is imported. The combination of these two factors made it hard for participants to imagine how a diversification of a castagnetu with shiitake would look like. However, one of the participants (Benjamin) has experimented with cultivating shiitake and oyster mushrooms indoors on straw and was very content with the results. Benjamin planned to grow shiitake and oyster mushroom commercially as part of a regenerative farm.

According to most participants, the marketing of shiitakes would not be an important issue. Even though the shiitake is not widely known or used in Corsican culture, it can be found in many supermarkets and other stores these days on the island and people regularly buy it. Moreover, selling shiitake to restaurants (where lots of tourists come) could be a good way to get premium prices for them.

However, one of the challenges is the costs of transport; most chestnut growing regions are far away from densely populated regions (mostly along the coast) and thus of potential buyers. Going down at least two times a week (as mushrooms do not store well) to the coast (where most densely populated areas are) to sell them could easily take three or four hours plus the fuel costs. One method to prevent this is to dry the mushrooms; shiitake can be sundried or with the help of drying machines and the drying process actually enhances the flavour. This enables a producer to store the mushrooms and sell whenever a retailer is found that wants to buy a reasonable quantity.

Based on the expertise of the farmers regarding the ecological conditions in the castagnetu, it seems like the conditions are favourable for the cultivation of shiitake: humid, shady (when the damage caused by the chestnut gall wasp disappears) and relatively cool which are all favourable conditions for the culture of shiitake outdoors (Mudge *et al.*, 2013).