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Faculty of Forestry and Wood Sciences

Department of Forest Management

Design of a spatial harvest scheduling for promoting mycological production

Diploma Thesis

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DIPLOMA THESIS ASSIGNMENT

Claudia Torre Agúndez

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Design of a spatial harvest scheduling for promoting mycological production

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Objectives of thesis

The main goal of the thesis is spatial harvest scheduling with respect to recommended silvicultural guidelines for enhancing mycological production. The next goal is quantifying the harvested timber volume and the economic revenue obtained throughout all the planning horizon when including the influence of the proposed silvicultural restrictions. Comparison of new proposed harvest scheduling and current scheduling defined by the Forest Management Plan is also one of the goals.

Methodology

1) The literature review focuses on harvest scheduling in Spain and spatial aspects influencing the mycological production

2) Editing potential harvest cuts for 3 planning periods (each 10 years long) in the ArcMap system.

3) Spatial optimization using DSS Optimal

4) Analyse of different combinations of harvest flow percentages and the size of clear cut

5) Formulation of recommendation for forest practise including mycological production aspect

The proposed extent of the thesis

40-50

Keywords

spatial harvest scheduling; ecosystem services; clear-cut management system

Recommended information sources

BOSTON, K. – SIRY, J P. – GREBNER, D L. – BETTINGER, P. *Forest management and planning.* Amsterdam ; London: Academic, 2009. ISBN 978-0-12-374304-6.

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DECLARATION

I declare that I wrote my diploma thesis independently, and that I have stated all the information sources and literature I used. Neither this thesis nor any substantial part of it has been submitted for the acquisition of another or the same academic degree.

I consent to the lending of my dissertation for study purposes. By affixing his or her signature the user confirms using this dissertation for study purposes and declares that he or she has listed it among the sources used.

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……………………………

Graduate's

signature

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ABSTRACT

Mushroom picking is a traditional activity in Spain that has been a traditional source of rural employment. Besides, it is well-known for not only being an important ecosystem service that provides several ecological benefits to the plants communities, but also for being a valuable recreational activity that is gaining importance in the last. Given its importance, many research has been carried out about how some silvicultural measures affect mushroom production and political and technical stakeholders have been carrying out legal actions and developing guidelines for the regulation and encouragement of this resource.

In this thesis it has been addressed for the first time the implementation of some of these guidelines in the design of a forest harvest scheduling. The subject of study is a forest in central Spain, in *Castilla y Léon* region. This forest has been traditionally managed for timber production since a long time ago, but it has been also the subject of the implementation of many innovative actions focused on enhancing the recreational use of the forest through mushroom picking.

From the background data of this forest and with the help of DSS Optimal optimization tool and a GIS framework, a spatial harvest scheduling has been designed. Three alternatives of different clear-cut sizes have been created. In addition, with the help of integer programming in the form of Unit Restriction Model, The Net Present Value and the Harvest Flow Volume of each alternative have been maximize subject to some adjacency and flow constraints that implement the requirement for encouraging mushroom production and sustainability of the management.

The results display the spatial and periodical distribution of the cuts during a 30 years horizon plan for each one of the alternatives. They also show the different values adopted by the objective functions. The analysis showcase that the obtained values are close or even higher that those expected in the current Forest Management Plan. However, some cuts belonging to the last age class will not be performed during the planning horizon. As that may compromise the actual even aged structure if the managers consider that the results are not desirable, it may be advisable to test the created design using a more flexible and accurate mathematical model that provide a wider variety of feasible results.

Keywords: spatial harvest scheduling, ecosystem services, clear-cut management system, mushroom picking

ABSTRAKT

Houbaření je ve Španělsku oblíbenou volnočasovou aktivitou, která je i tradičním zdrojem obživy na venkově. Kromě toho je dobře známo, že nejenže je důležitou ekosystémovou službou, která poskytuje rostlinnému společenstvu mnoho ekologkých přínosů, ale je také je cennou rekreační činností, která v poslední době získává stále větší význam. Vzhledem k jejímu významu bylo provedeno již mnoho analýz o vlivu některých činností lesního hospodářství na produkci hub a i o právních krocích politických a správních subjektů ve spojistoti s regulací a podporu tohoto zdroje.

V této práci byla poprvé řešena implementace některých těchto směrnic při návrhu plánování lesních těžeb. Předmětem studia je lesní majetek ve středním Španělsku, v regionu Castilla y Léon. Tento les je tradičně hospodářský s jasným cílem produkce dříví, ale je také místem realizace mnoha inovativních akcí zaměřených na zvyšování rekreačního využití lesa při houbaření.

Z informaci o lesních porostech tohoto majetku a s pomocí optimalizačního nástroje a GIS byl navržen prostorový plán mýtních těžeb. Byly vytvořeny tři alternativy podle zadaných parametrů optimalizace. Pomocí celočíselného programování byla maximalizována celková výše těžeb s ohledem na prostorové přiřazování sečí a podmínek plynulosti těžeb, které jsou důležité pro trvale udržitelné hospodaření s lesním ekosystémem.

Výsledky zobrazují prostorové periodické rozdělení těžeb v průběhu 30 letého horizontu pro každou z alternativ. Prezentovány jsou také různé hodnoty získané alternativními účelovými funkcemi. Analýza ukazuje, že získané hodnoty jsou blízké nebo dokonce vyšší než hodnoty očekávané v současném lesním hospodářském plánu. Některé těžby patřící do poslední věkové třídy však nebudou provedeny v rámci následujících 30 let. Pokud by manažeři lesního majetku usoudili, že výsledky nejsou žádoucí z důvodu narušení vhodné věkové struktury, mohlo by být vhodné otestovat vytvořený návrh pomocí pružnějšího a přesnějšího matematického modelu, který poskytuje širší paletu proveditelných výsledků.

Klíčová slova: prostorové plánování těžeb, ekosystémové služby, holosečný hospodářský způsob, sběr hub

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1. INTRODUCTION

Mushroom picking is a traditional activity in Spain since a long time ago. Is has been a remarkable income source in rural areas. Since the last century it has gained importance as a recreational activity for people that live in cities and seek for some weekend close-to-nature activities.

In parallel to this increased interest, many researchers have driven several studies about the symbiotic relationships between the mushrooms and their habitats. Their studies focus on various approaches. For instance, how different species growth trends differ, how production changes among the seasons or the influence of the trees age class in the amount of production.

In spite of all the theoretical information about this topic there is no empirical evidence that directly relates changes in the silviculture measures with a certain degree of improvement on the mushroom production.

However, several studies point out the strong influence of the size of the cuts in the persistence of the mycelium after the trees removal. All this information has been gathered and taken into account to develop some silvicultural guidelines whose aim is to enhance mushroom production. Those guidelines are adapted to the particularities of the different ecosystems that are mushroom producers.

In the last 20 years, the forest managers of *Castilla y León* region, along with the help of the researchers and political stakeholders have made efforts to encourage a sustainable use of this resource, and at the same time, to promote this activity as an example of a multipurpose use of the forest that is beneficial from the economical, from the social, and from the environmental point of view. The result of their aim has been the development of a legal regulation that ensures an economic revenue for the private owners and provides a legal support good practice to the users and also the development of information tools to help the users make a right use of the resource and make the most out of their touristic experience.

In spite of all the efforts made in the direction of promoting mushroom picking, in terms of the Forest management, the silvicultural guidelines have not been totally implemented and the Management Plans do not specifically intend to implement measures towards the promotion of this resource.

Mathematical programming can recreate future scenarios and so it is a very useful tool for managers to let them see in advance the effect of their measures. In terms of forest management, integer programming, with the help of geographic information systems (GIS) allows designing a spatial forest scheduling and creating a model including some silvicultural restrictions. In the case of testing a particular silviculture for mushroom production, the solution will convey the information about the effect of putting the proposed measures in practice.

2. GOALS

The goals of this diploma thesis are the following: First of all, to create a spatial harvest scheduling that implements the recommended silvicultural guidelines for enhancing mycological production. Secondly, to quantify the harvested timber volume and the economic revenue obtained throughout the entire planning horizon when including the influence of the proposed silvicultural restrictions. In addition, to make a comparison between the new proposed harvest scheduling and the current scheduling defined by the Forest Management Plan. And finally, to test the viability of the developed model for is implementation in practice.

3.LITERATURE REVIEW

3.1. Forest management in Spain

3.1.1. The Forest in Spain

Spain is a very diverse country. It gathers six Köppen climatic zones (Kottek et al, 2006), oceanic climate mainly in the north-west coast, Mediterranean continental climate in the central high plain, Mediterranean climate in the south and by the east coast, semi-arid climate in the south-east coast, alpine climate in the mountains zones and subtropical climate in the Canary islands. Regarding soil types, there is a marked difference between oceanic zone soils and Mediterranean zone soil. Oceanic soils lay over acid bedrock and are rich in organic matter. Within the Mediterranean soils in the west part of the territory acid and oligotrophic bedrock prevails whereas in the eastern part, over limestone bedrock soils appears a horizon rich in clay and they vary in the presence of nutrients. However, the most common soils in the easternmost part are intrazonal and eroded limestone soils (Porta, 2003).

The climatic variance joint to the marked difference between soil types lead to the existence of a broad range of ecosystems with their own features that have to be treated specifically for all the stakeholders in charge of their management.

Moreover, the country is divided administratively into 17 Autonomous communities which are territorial entities endowed with some legislative autonomy, their own representatives and certain executive and administrative power. This structure is recognized in the Spanish Constitution of 1978, the supreme law of the Kingdom of Spain (Constitución española, 1978).

According to their Autonomic Statutes, each Autonomous Community is attributed full competencies in legislative development about ecosystem protection and everything related to forestry, being always under the frame of the State's basic legislation stated by the Law 41/2007 of Natural Patrimony and Biodiversity and Law 43/2003 of Forest Land (Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad and Ley 43/2003, de 21 de noviembre, de Montes).

Castilla y León is a territory located in the northwest of Spain that has no contact with the seashore and is the largest of all Autonomous Communities, occupying a surface of 9,422 thousand hectares. It is likewise subdivided into 9 provinces. The entire territory is more or less equivalent to the watershed of the Duero river so morphologically the centre is occupied by high plains and is surrounded by several mountainous formations.

Figure 1. Castilla y León political map and provinces. Source.JCyL

With respect to forest management the separation of competencies may help to address the particular features of the ecosystems found within the boundaries of each Autonomous Community. Particularly, in Castilla y León region, the "Law 4/2015 of Castilla y Leon's Natural Patrimony " and "Law 3/2009 of Castilla y León's Forest Lands". (Ley 4/2015, de 24 de marzo, de Patrimonio Natural de Castilla y León and the Ley 3/2009, de 6 de abril, de Montes de Castilla y León) provides legal instruments that regulate everything related to ecosystems and their use.

The typical climate of the region is Mediterranean Continental (Kottek et al., 2006). This means that the main climate characteristics regarding the rainfall regime are those of Mediterranean climates, but being far from the seashore the temperature range is much wider. In general, winters are wet and cold, and temperatures are often below 0ºC. Summer is the driest period, matching with the highest temperatures. Annual rainfall is characteristic of Mediterranean climate, being from 450 to 600 mm (García Fernández, 1986). These climatic features in addition with the remarkable orographic variation configure a broad variety of forest ecosystems within this territory and therefore involve a broad variety of forest management types (López Leiva, 2009).

From a territorial point of view, out of a total surface area of 9,422 hectares, 51% consist of forestland, which is 41% the average value in the European Union. An entire 32 % corresponds to tree-covered forestland and reaches 2,982 thousand hectares (Junta de Castilla y León, 2014).

Regarding ownership and an entitled management body, the surface under private management is 2,894 thousand hectares in contrast with the forest under public management that is 1,923 thousand hectares. Private management relates to those under private ownership .The forest under public management can be identified with the Public Utility Forest that belong to public entities and also the private forest that have is under contract with the public entities (Junta de Castilla y León, 2014b).

The main types of forest communities that we can find in this region, according to the Third National Forest Inventory (Junta de Castilla y León, 2014b) are:

- Broadleaved forest of *Quercus robur*, *Quercus pretraea* and *Quercus pyrenaica* with open and close canopy,
- Broadleaved forest of *Quercus ilex*, *Quercus faginea* and *Quercus suber* with open and close canopy,
- Juniper groves *(Juniperus oxycedrus* and *Juniperus thurifera*),
- Beech forest (*Fagus sylvatica*),
- Productive poplars (*Populus x euramericana* and others),
- Chestnut groves (*Castanea sativa*),
- Mix of conifers and broadleaves and
- Mix of juniper groves and broadleaves.

In addition to the aforementioned, the typical productive stands are dominated by pinus species. In *Castilla y León*, forest surface occupied by pure pine tree stands is 840,000 ha (Junta de Castilla y León, 2014b). The most typical pine tree species that we can find are *Pinus sylvestris, Pinus nigra, Pinus pinaster, Pinus radiata and Pinus pinea*. The typical communities of pine trees that can be found in the specified region are:

- Mountain pine forest of of *Pinus sylvestris, Pinus nigra or Pinus uncinata,*
- Productive pine forest of *Pinus pinaster or Pinus radiata,*
- Other pine stands of *Pinus pinea and Pinus halepensis.*

3.1.2.Methods of harvesting planning

Focusing on the management of pine forests with respects to silviculture, the desirable structure for productive stands is high forest of even-aged stands (Serrada et al, 2008). For achieving regeneration, these stands are treated by several silvicultural methods, such as clear-cuts, Shelterwood method, Seed Tree method or less commonly by Selection method. The productive pine tree stands usually undergo several forest management systems based on different harvest scheduling for the goal of creating the even-aged stands. The simplest one of them consists of dividing each management unit into some cutting units so that each of the cutting unit belongs to an age class that has been regenerating for 20 years. This system is called the Periodic Block Method. After the cutting cycle, that usually lasts 100 to 120 years for most of this pine tree species, patches of all artificial age classes that form an even-aged stand structure form the area of the forest. Depending on how the cutting areas are formed we have some other forest management systems (Sociedad Española de Ciencias Forestales, 2018)

- Area control method: the cutting areas are formed according to the annual allowable cut.
- Single block method: the cutting areas that will undergo a regeneration period are gathered in a management unit called a regeneration block. The stands that form the regeneration block can only be regenerating during a single regeneration period
- Area control method: the cutting areas are formed according to the annual allowable cut.
- Floating periodic block method: it is a variation of the previous method, in which the stands that form the regeneration block can still under regeneration during one, two or three regeneration periods.
- Management by stands: is a method that allows managing forest implementing different cutting cycles within the same felling area where the surfaces are so small that all age classes can not be represented.

The managers choose for each forest the system that best suits the forest characteristics and the goals of the management. For instance, the last method was born as an answer for the new multipurpose management approaches that have been implemented in the planning since the society is more concern about sustainability and responsible use of natural resources (González Molina et al., 2006). Multipurpose forest management allows the integration of many resources in management, such as the production of several goods, recreational, scientific, protection and is based on studying the compatible relationships between them.

3.2. Mushroom Harvesting in Forest Management

3.2.1. Importance of mushroom picking

In the *Castilla y Leon* region, non-commercial mushroom harvesting has been proven by studies, to be highly popular and of high interest a great demand (Frutos et al., 2009; Martinez Peña, 2003).

Mushroom picking is a very traditional activity in the rural areas of this autonomous community. The most typical non-commercial species that live in this regional forest ecosystems are regarded as some of the most valued species worldwide (Oria de Rueda et al, 2011): *Boletus* gr. *edulis, Lactarius* gr. *deliciosus, Morchella spp, Cantharellus cibarius, Tuber melanosporum, Amanita caesarea, Calocybe gambosa Marasmius oreades, Pleurotus eryngii, Tricholoma portentosum, Tuber aestivum, Hygrophorus spp, Hygrophorus marzuolus, Helvella spp, Lepista spp, Macrolepiota spp, Agaricus spp,* etc.

According to the historical review made by (Oria de Rueda et al., 2011), during the 18th and 19th centuries, mushroom picking gained its commercial viability through traditional market places and sometimes the intensity of the harvesting pressure caused the need to limit the allowable area for mushroom picking.

During the 20th century, along with the development of the transportation came the growth of the edible mushrooms market. Since the 50s some food industries started to create elaborated products based on edible mushrooms in brine. The production was sold throughout the country.

In the 70s, the invention of refrigerated trucks created the possibility of preserving fresh mushrooms to be sold after travelling long distances. By this time most of the collectors harvest for commercial purposes and this fact increases when is possible to send harvests by plane through transoceanic flights.

At the end of the 20th century globalization caused a raise in competence of other exporter countries. However, at the same time, since the 90s, the recreational and non-commercial mushroom picking demand has been growing exponentially due to better connectivity. This has led to the creation of a new economic activity that is called “myco-tourism” that is helping rural development but involves the need for a proper regulation that ensures the sustainability of the resource. In answer to this necessity, the Law of Forest Land 43/2003 (Ley 43/2003, de 21 de noviembre, de Montes) recognized at the state level and for the first time mushrooms as a property that belongs to the owner of the land. This opened the door to the regulation of their harvesting.

Nowadays, mushroom picking involves the 54 % of the *Castilla y León* rural population, around 600,000 mushroom pickers. Only 14 % of this population is selling, however, this means there is a yield of around 17,000 tons in a productive year. This amount could generate direct incomes close to 65 million Euros. This economic output could generate 300 or 400 direct workstations in *Castilla y León*. In addition, the non-commercial picking, which represents 40 % of the population could generate incomes of around 33 millions Euros per year (Martínez-Peña *et al.*, 2011). Even during an average productive year, in Martínez-Peña et al. (2011) a potential harvest is estimated at about 6,000 tons of commercial mushrooms, which when combined with the potential 30 tons of *Tuber melanosporum,* may generate total incomes of 33 million Euros. This would mean enough supply for the establishment of 30 or 40 enterprises. In fact, in 2008 there were 36 enterprises located near to the mushroom sources, mainly specializing in processing and selling mushroom (Martinez-Peña, 2008). This data explains how relevant this resource is for the economic development of rural areas.

Myco-tourism is another way of bringing incomes into rural areas. It is about joining mushroom production with recreational use and it generates indirect economic value in the form of tourist services, accommodation, restaurant services and any other expenses during the visit. In an average year it brings 40,000 tourist, that generate about 120,000 night stays. The 54 % of accommodation facilities host myco-tourists. Martínez-Peña and García-Cid (2003) conducted a survey in Comarca de Pinares that showed that foreign tourists come 2.8 times a year and they stay for 2.3 days on average. The 93.6 % of them used some tourist service, the 35 % visited restaurants and the 43.5 % paid for accommodation (those aforementioned restaurants the 52 % of them include wild mushrooms in their recipes and in last years there are many events for promoting wild mushroom gastronomy, such as “MercaSetas” (“MushroomMarket”) in Molinos de Duero in 2015 or “MercaTrufas” (“TruffleMarket”) in Soria province the same year (www.micosylva.com)

3.2.2.Micology regulation in Castilla y León autonomous community

Edible mushroom harvesting has been under regulation in Castilla y León since 1999. The Decree 130/1999 (Decreto 130/1999, de 17 de junio) regulated mushroom harvesting in *Castilla y León* forest by setting some general measures that have to be followed, defining some prohibited practices and establishing three different types of harvesting: episodic, commercial or local and for scientific purpose (Lucas, 2011). This differentiation set a basis for the design of the licenses system. Nowadays, the current legal instrument is the Decree 31/2017 (Decreto 31/2017, de 5 de octubre) of regulation of the wild mycological resources in *Castilla y León.*

The “Junta de Castilla y León” (the Autonomous Community governance and administration body) has been working in the promotion of mycology since 1989. Since then, they have developed a Forest Mycology Program that has been internationally recognized. Martínez Peña (2011) introduces a brief description of the regulation's development. First of all, in order to achieve the program’s goals it was created a unique Research Centre in Valonsadero (Centro de Investigación Forestal de Valonsadero, Soria) whose aim was to measure the production and diversity of the forest mycology as well as to promote the activity of mushroom picking within the society.

In 2001, thanks to the cooperation of the researchers and the support of political actors of the region, along with the complementary help of the European Commission; The project MYAS was born (PROYECTO LIFE/00/ENV E/544 MYAS) with a surname that showed its aim: “towards a model for improving the value and for mycology sustainable management”. This first project was followed for two more projects of inter-territorial cooperation: ”Mycology and Quality (2004-2006)” and “Mycological resources and Rural Development” (2006-2007).

The regulation started between 2003 and 2004. It required a single harvesting regulation authorization document for every forest. The price for the first year was the amount of 0.1 €/ha. That year was a great success and they issued 4,479 licenses. In 2006 from the Valonsadero Research Centre it was created a Web-based information service called “Micodata”, a platform from which to gather information about mushroom identification, good harvesting practices, production and the state of regulated forests. Information about production potential is displayed through MicodataSIG, a GIS based on a descriptive model. Moreover, there is also a service for species identification (Martinez Peña et al., 2011). Nowadays this service can be found at www.micocyl.es.

The next step towards regulation was made in 2008, thanks to the MYAS RC (2008-2012) project for “regulation and commercialization of mycological resources in Castilla y León”. The project lasted until 2012 and was provided with financing of 3,360,000€. The latest effort for implementing the regulations was made in 2009 by the project INTERREG IVB SOE1/P2/E069 MICOSYLVA “Silvicultural management of forest producers of edible mushroom economically valuable, as a source of rural development” that gathered eight European partners and twenty-four associate partners from EU, Switzerland, Canada and USA. Nowadays the collaboration between those countries resulted in the creation of an international network of areas that are an example of multifunctional use of the forest based on myco-silviculture.

The regulation system currently existing consists of issuing some licenses with different typology and prices. Some guidelines have to be followed. The optimal number of issued permits is defined by taking into consideration certain criteria such as sustainability (reception capacity), demand satisfaction and representation of the different types of permits (Aldea et al., 2011). With regard to legislation mushroom picking is divided in three categories: commercial, with scientific purposes or episodic. Commercial or local has to be indicated in the Annual Harvesting Plan of the forest and needs and administrative authorization. Scientific picking requires the authorization provided by the owner. Episodic can be regulated by municipality's regulation and issued episodically. Each one of these categories is related to some picking allowance. Only 5 kilograms are allowed each day for recreational license, and the commercial license allows picking up to 50 kilograms per day. In addition, there are one or two day permits, seasonal permits and special permits, which mean different prices. The prices are also different if the pickers are local, foreigner or associated, which means someone that may not live in the region but has proven some relationship with it (Vega, 2011). Table 1 shows an example of the settled prices in the forest of the Soria province that belong to the Mycologycal Management Unit (MMU) "Montes de Soria" (source: www.micocyl.es).

Table 1. Permits typology in "Montes de Soria"MMU

PERMITS TYPOLOGY			
Validity	**Type of harvester**	**Cost per type of use (€)**	
		Recreational	**Commercial**
Seasonal	Local	3	10
	Associated	5	50
	Provincial	40	300
2 days	Foreigner	5	-

Source: www.micocyl.es

3.2.3. Forest management and mycology in “Comarca de Pinares”

The "Comarca de Pinares" region is located in the Northwestern part of the Soria Province, which is the easternmost end of the *Castilla y León* nine provinces. It represents about 100,000 hectares of the typical natural mountain pine tree forest, hence its name means, “Pine Forests County". The location of the Soria province is displayed in the Figure 1 and the location of the "Comarca de Pinares" within Soria is showed in Figure 2.

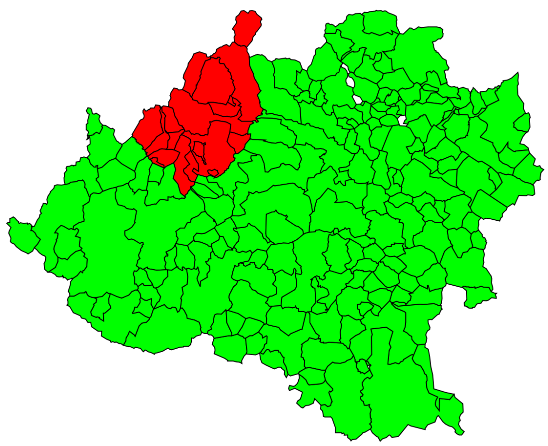

Figure 2. Location of "Comarca de Pinares" in Soria province

Most of the forests in this region are a Public Utility Forest and the majority belong to the 23 municipalities. Locals have traditionally been using the goods provided by these forests for ages. They developed a small industry dedicated to timber harvesting and transformation and wood-based product production that involved a steady source of employment opportunities. The locals became attached to their forestland and that is why such a low rate of forest fires occurs in this region as compared to others. Another example that shows what this relationship means is the so called “suertes de pinos” (“pine privileges”). This designation refers to a privilege that the locals had over forest harvesting and has existed since the end of the 13th century. In practice it means the right for felling some amount of pine per persons each year, and for some centuries this supposed the that the felled trees were chosen among the best of the region. This fact unsustainable harvesting used the need for implementing a proper forest management. Before applying forest management such as we know nowadays, some basic silviculture practices were done, such as selective cuttings, but livestock was free and overexploitation and traditional use of fire was a common issue (Lucas, 2001). In the beginning of the

20th century the Forest Administration started the development of forest management plans for the most important forest stands, such as Pinar Grande in 1907, and Santa Inés in 1924 (Lucas, 1995). This led to a transition of even-aged structure that ensures the sustainability and the quality of the stand by for instance, the protection of the regeneration from livestock, among other ecological improvements. Nowadays, the forest under public management estimated growth is 505,000 m^3 per year and the forest under private management yields a growth of 70,000 m^3 per year in this region (Junta de Castilla y León, 2014). This region is an example of how sustainable use of the forest can ensure the development of rural economy and at the same time be beneficial from a social, economic and environmental perspective (Lucas, 2001)

Regarding ecological features, the type of habitat found in "Comarca de pinares" , in relation to mushroom production fits perfectly to the description of the type "Hygrophilous and Silicate Mountain pine forest of *Pinus sylvestris* producers of *Boletus gr. edulis* " defined in Oria de Rueda (2011). The description tells that this kind of pure *Pinus sylvestris* forest is often found accompanied with *Pinus pinaster*, in sites where the rainfall is over 600 mm and soil reaction is acid. These forests have the perfect ecosystem for producing *Boletus edulis* and *Boletus pinophilus*. Other featured species are *Lactarius deliciosus* (L.) Gray, *L. sanguifluus* (Paulet) Fr., *L. vinosus* Quél., *Tricholoma portentosum*, *T. terreum*, *Hydnum repandum* L., *C. cibarius*, *C. tubaeformis* Fr., *Sarcodon imbricatus* (L.) P. Karst, *Hygrophorus marzuolus* (Fr.) Bres., and so on.

A lot of research has been driven in this area due to its traditional mushroom picking demand. The results of these studies have been taken into consideration to serve as the background information used to develop mycological regulation. For instance, given the difficulty to measure the high variability among species, among forest and among years, there is not much data about productions. For this reason the managers have made some efforts to gather such information, given the needed to do a proper regulation of the good (Oria de Rueda et al. 2007). From 1995 to 2009 a research about production was carried out in the "Pinar Grande" forest. Eighteen permanent plots representing different tree age classes were sampled. The result showed the production of several mushroom species over those years (Ortega-Martínez et al., 2011). It was found that Boletus production reaches around 20 kg/ha when the stand age is from 35 to 60 years old. The production rises to 40-60 kg/ha when the stand age is between 50 to 90 years old. After these study results and for the aim of developing The MicodataSIG (GIS) tool (a descriptive model of the production of different mushroom species) the developers settled some representative average production values. Particularly, in the forest type "*Pinus sylvestris* producer of *Boletus edulis"* the average annual yield of *Boletus edulis* was settled as 15 kg/ha and for *Boletus pinophilus* as 10.25 kg/ha. *Lactarius gr.deliciosus* yield was 15.25 kg/ha. These values were assigned considering optimal climatic and ecological conditions (Martínez Peña, 2011).

The market price of edible mushroom species is varies during the season and among the years. Besides that it is strongly influenced by the international market. After the surveys targeted to harvesters and related enterprises and marketplaces, the prices that the picker receives for *Boletus edulis* range between 3 and 10€kg for the harvester (being 5 € the average) and the price paid in the retail market ranges from 12 to 25 €/kg (Oria de Rueda et al., 2011).

Regarding spatial distribution of the production, after comparing total production sampled in the different zones of the case study forest it was found that the 53% of the gross production was harvested in trough areas whereas 32% was harvested on the hillsides (Martinez-Peña, 2003). These results show different visitors behaviour patterns when it comes to preferences in mushroom picking areas.

Regarding the final destination of the production, after a study conducted by Ortega-Martínez and Martínez-Peña (2008), it was found that in Pinar Grande from the total production, 24 % *of Boletus edulis* production is harvested, whereas 7 % is consumed by cattle, 26 % is damaged and 15 % stays un-harvested. Other forests of the same region, after being monitored for *Lactarius* gr. *deliciosus* production showed that only 24 % was harvested.

Since the implementation of mushroom picking management in 2011 the licensing system allows having a reliable source of information about the number of licenses issued each year. The number of issued licensed shows great variability among years, as a direct reflection of the variablity of the production. Table 2 shows the number of licenses issued in the MMU "Montes de Soria". This management unit includes around 250 forests, several of which are the "Comarca de Pinares" forests. Besides that this unit is quite representative as it involves the 40 % of the total regulated area within *Castilla y León* region. From the Table 2 it can be seen the differences between a good production year (2015) and a bad production year (2016).

Table 2. Example of issued licenses in "Montes de Soria" MMU

Year	Number of licenses	Profit €/ha
2015	57.332	1,43
2016	13.360	0,13

Source: Lucas Santolaya,J.A. Direct communication

Apart from this empirical data, de Frutos et al. (2009) estimated the recreational value of this study area, which showed that the value varies between 6 and 14 € per hectare. Besides that, they also focused on the impact of mushroom picking as a source of income and employment in the whole region. The result displayed the number of day trips and overnight stays related to this activity and pointed out their importance as a source of employment in the off season.

3.2.4. Mycosilviculture

The benefits of mushrooms in any ecosystem level are broadly known. Not only for their contribution to species biodiversity but also for the symbiotic relationships between them and the plants: this beneficial interaction makes any change in the composition or state of the fungi very influential to the tree individuals associated. Between 85% and 95% of vascular plants create mycorrhyzae (Fernandez Toirán, 2011). Particularly, *Pinus* species create ectomycorrhizae. This kind of relationship helps to improve the absorption of essential nutrients, such as nitrogen and phosphorous.

Mushroom production depends on several factors such as climate, soil type, soil reaction, host species and host structure. (Bonet et al., 2008, 2010; Egli et al., 2010). However, the edaphic and climatic factors are the most influential (Bonet et al., 2008) and those can be partly modified by silviculture. Including mushroom silviculture in a way to improve the traditional silvicultural system by taking into account the influence of these valuable organisms.

Mycosilviculture is the set of forestry techniques for the treatment of the forest in order to improve the production of edible mushroom. It is based upon the knowledge of environmental conditions that affect their growth, their presence and reproduction and take this knowledge into account when designing silvicultural treatments for a particular forest (Oria de Rueda, 2011).This kind of silviculture can promote not only mushroom species but tree and animal species and its extra value lays in the fact that it is a way for implementing other valuable resource in the multipurpose forest management. According to Martinez-Peña (2011) there are some main criteria for conservation and improvement of mushroom production and diversity and each one of them has their own practical ways of being integrated in forest management:

- First of all, to provide a source of inoculum after disturbances: It is proven that production and diversity of fungi decreases significantly during the 15 years after the final cut, and totally recovering 30 years after (Martinez-Peña, 2008). The hyphae of the mycorrhizal fungi can only grow out into the soil from 5 to 15 cm from the infected root (Brady & Oliver, 1974,) hence the source of inoculum has to be as close as possible to the new seedlings. A study about the diversity of ectomycorrhizae mushrooms after clear-cuts in a British Columbia subalpine forest showed that, although there were no differences in diversity found the year after performing clear cutting of 0.1 ha, 1 ha and 10 ha, there was a significant decrease in presence an diversity during the second and the third years after the cut when increasing the distance from the edge of the adjacent forest. This finding suggests that the smallest cut areas are recommended in order to better preserve ectomycorrhizycal mushroom diversity (Hagerman et al., 1999). Therefore, after carrying out any regeneration cut that involves a significant removal of trees it is necessary to consider how to maintain enough of the source of inoculum to minimize production decrease. This can be done by the conservation of shelter plants, advanced regeneration and overgrowth trees. For this purpose the Seed Tree Method is recommended, in addition to retaining advanced regeneration. Another means of fulfilling this criteria is keeping a high perimeter/area ratio: the inoculum source will infect more easily in a strip shape rather than clumps for the same surface. Besides, a crooked perimeter is the most desirable option (Oria de Rueda et al., 2011).

- Secondly, to conserve and promote mushroom production: Most of the edible mushrooms are light demanding (*Boletus*, *Lactarius*) so first and foremost it is essential to avoid growth slowdown of the stands. Unmanaged forests lead to high densities and huge competence. That is why tending and carrying out improvement cuts are always recommended. In managed stands there is interest in keeping moderated basal areas, which can be controlled through pre-commercial cutting and thinning. According to Bonet et al. (2008), an optimal basal area is around 15 m^2/ha. After an opening in the canopy production is stopped for not more than 5 years but afterwards it increases significantly (Fernández Toirán,1994; Oria de Rueda et al., 2007). This light demanding character joined to the need of a close location of source trees is the reason that the most recommended cuts for fungi production are Group Selection cuts (Oria de Rueda et al, 1999). This involves that the recommended area without tree cover within a block is smaller than the usual regeneration area applied in Spanish productive pine stands when clear-cuts or shelterwood method are applied in a block. Oria de Rueda et al. (2008) proposed an intervention between 0,2 ad 1,5 ha big whereas the typical recommended clear-cut area for this ecosystem is smaller than 5 ha but with a maximum of 10 ha in the *Castilla y León* region (Jiménez et al., 2006).
- Moreover, to maintain a diverse mushroom community: First and foremost, it is necessary to promote a quick regeneration after perturbation because within 1 to 2 years without plant host the population decreases substantially (Hagerman et al., 1999). Also, promoting tree species mixture given that trees are more likely to associate with a wider variety of fungi species when they live in mixed stands with other species (Oria de Rueda et al., 2007). Another recommendation is to protect the indigenous mushroom species is promoting indigenous tree species and controlling alien species. In addition, for every stage of the forest there is a particular mushroom community associated with it, therefore, promoting a high diversity of forest ecosystems is beneficial given that the patched structure of the forestland

encourages fungi diversity. Hence, Group Selection System is equally preferred because it creates a big diversity of habitats as well as providing enough inoculum source after regeneration cuts. As one of the forest management principles for maintaining sustainability and diversity is keeping a forest structure where all age classes are represented this is also beneficial for the mushroom. This structure allows having an annual production of different mushroom in the same stand, as different species are associated with different age classes. Some of them are pioneers, fruiting between 0 and 20 years (*Lactarius gr. deliciosus*), some other are secondary (between 15 and 40 years) and the latter of them fruit from 30 and so on. In the case *of Boletus gr. edulis* the fruiting starts between 40 and 50 (Oria de Rueda et al., 2011).

- Last but not least, to enhance the stability and variety of soil habitats and microhabitats: Removing wood after cuts or other disturbances by non-aggressive means and by a good planning of logging routes. Animal means light skitters are preferred for this task over traditional machinery because they reduce soil compaction (Oria de Rueda et al., 2007). In addition, using soil preparation techniques such as a slight scarification avoids damaging mycelium.

To sum it up, small clear-cut sizes are recommended not only for the stated reasons but also for some other side effects of applying these sizes that have to be considered for its importance: First of all, the positive influence in the landscape quality. The arrangement of patches creates heterogeneity inside an area where all the trees will belong to the same age class. This heterogeneity is expected to increase the value related to scenic beauty (Surova et al., 2014) The fact that there won't be seen big areas without forest cover or quite small trees will create the feeling of a more continuous cover and is expected to generate a less visual impact. In addition, the scenic beauty will be enhanced by the closer distances between trees with high diameter and height (Silvennoinen, 2014). The landscape quality influence is even more meaningful in this particular forest because of its recreational features. A great amount of visitors explore the whole area of the forest in search of mushrooms, not only near the paths or forest roads but also many of them arrive to the hillside zones (García Serrano, 2018).

From an environmental point of view this scheduling will enhance soil protection and diminish erosion and soil loss. It is also recommended for biodiversity conservation as a means for improvement of the connectivity (Gonzalez-Molina & González-Romero, 2006).

Nowadays it is a trend in the forest policies of some European Countries to restrain the allowable area cut. For instance, in Czech Republic the area must not exceed 1 hectare, or in exceptional cases such as pinewood stands in sandy soil, they are of 2 hectares (Act on forest, 1995). It is expected that some of these considerations may be taken into account in the future in Spanish forest policies and they were therefore included as legislation restrictions.

Although the Group Selection System is the recommended regeneration treatment it has to be pointed put that this is a typical treatment for creating an uneven-aged stand but in the case of productive pine tree stands the reasons for maintaining the even-aged structure are numerous. The most important of them is that in ecological terms, it is the recommended structure for achieving the natural regeneration of these pine species given that the species tendency is to close the canopy and therefore to suppress the stratification underneath (Gonzalez Molina & González Romero, 2006).

3.3.The use of Mathematical Programming Forest Management

Apart from the traditional management planning new techniques have been developing in the last 40 years (Rönnqvist, 2003). Mathematical programming is a tool that allows the managers to know the economic impact that can produce different scenarios by applying several alternatives. By their use we can obtain some results that are impossible to know using the traditional management systems. The knowledge provided can be very useful for the managers and owners in their decision-making processes.

3.3.1.Integer Programming in Forestry

Integer programming is a classic mathematical optimization method in which the variables are integers. When the unknown variables are displayed in a binary form it is called Binary Programming: a specific type of Integer Programming. The objective function and other constraints can be linear so is often found in the literature as Integer Linear Programming.

There are many different types of problems in the forestry field that can be solved using this optimization model. Weintraub (2007) describes the typology of problems most commonly approached. The first outlined problem was “the road building problem”. Its goal was to optimize the access of road services to a harvested area. It was solved in the 80's and used for the US Forest service afterwards. Another kind of problem is the “machine location problem” that describes the most efficient way to locate harvesting machinery and road accesses. The “spatial harvesting model” is one of the most basic linear programming models and basically it helps to decide which areas to harvest to satisfy the demand in each period of a planning horizon.

The use of this mathematical programming in spatial harvest scheduling problems has gone along with the development of computer software of GIS. It is also strongly related to the societal change of values associated with environmental concerns (Shan, 2009). Maintaining sustainability and enhancing ecology is a big a concern nowadays that can be addressed including constraints in the harvest scheduling.

Integer programming used for Spatial Harvest scheduling allows optimizing the economical benefits by deciding which areas to harvest in each period of time while including environmental restrictions related to the shape and size of the management units. The results can be displayed in a GIS. Moreover, it can include some other silvicultural and economical restrictions such as balance of the harvest flows or balance of the age classes' area. That is to say that it allows studying in advance the influence of including certain restrictions in management and so it allows the user to compare different alternatives with the actual forest management (Rönnqvist, 2003).

Some examples of studies based on integer programming for solving management problems were used in Kašpar et al (2015a) for solving a harvest scheduling problem for multipurpose forest management including timber production and nature conservation. Spatial constraints were included to consider the overly matured reserve area while maximizing the amount of harvested timber. Marušák and Kašpar (2015) also studied spatial-limited harvest scheduling for small-scale shelterwood and clear-cuts systems including some unharvested patches for considering environmental protection. As an example of this, Fonseca et al. (2012) created a model with five different scenarios for the planning of clear-cuts and thinning regime *Pinus Pinaster* in North Portugal.

3.3.2.The Unit Restriction Model

Including spatial restrictions to harvest scheduling by integer programming can be done in two main ways: through Unit Restriction Model (URM) or through Area Restriction Model (ARM). The first approach consists on defining a maximum area required for each management unit (Barrett et al., 1997). The model is based on the assumption that each management unit size is below a settled area limit so, therefore, it is inherently included the restriction that does not let two adjacent units be treated at the same time. The Area Restriction model approach is based on setting the condition that the area of the management unit has to be significantly below a certain limit. However, in this case, adjacent units can be treated at the same time as long as their total area does not exceed the limit and therefore the obtained results are a big number of possible combinations of contiguous areas that fulfil this condition.

ARM is a more precise method for obtaining optimal harvested areas. As an example, it has been successfully used in Kašpar et al (2016) to develop a new spatial harvest scheduling in a commercial Eucalyptus plantation in Brazil. The goal was maximizing the Net Present Value and annual balanced harvested volume while including spatial constraints such as the maximum distance between harvested areas. The environmental goal was to preserve soil from erosion and wildlife protection. After comparing the URM and ARM it is proven that, although it provides better objective function values than URM given the same problem but, as is a non linear method, finding feasible solution is not computationally bearable without the help of heuristic methods even for simple problems (Murray, 1999).

There are different adjacency constraints used for solving the Unit Restriction Model. After comparing different types of adjacency constraints, Kašpar et al. (2016b) proved, that pairwise comparison is the most efficient type, compared to other analytical algorithms.

The basic model consists of the following expressions (Murray, 1999): It starts with defining an objective function to maximize. This function is composed by a value associated to each unit and the decision variable. The solution implies whether or not to cut in a period. The equation gives the total harvested value. This objective function is maximized subject to, first of all, a constraint that ensures that each harvest unit will only be harvested once. Then, a constraint is needed hat ensures that adjacent units are not harvested at the same time (given by a adjacency matrix). In addition, a constraint that ensures that the amount of harvested wood will be inside the allowed range of harvested flow. Finally, to accomplish the desirable type of integer model it is necessary to have a constraint that ensures that the decision variables are integer. Furthermore, the model can be extended by adding some other constraints if additional problem solving is needed.

The complexity of the model increases with the number of harvest units and with the average number of adjacent harvest units. The difficulty in solving by using exact methods can be solved by improving the structure of the adjacency constraints by for instance including some coefficients for relaxing the impositions of the restrictions (Murray and Church, 1996)

Some examples of the use of Unit Restriction Model were tested in Snyder and ReVelle (1996). They used it for the maximization of harvested timber over different time horizons for an irregular system through applying adjacency constraints.

3.3.3. Optimization of recreational aspects

Forest management optimization of recreational aspects is a field that has yet to be developed. There is a lack of model for non-timber products (Calama et al. 2010), and therefore the ones focused in recreational aspects. Their profitability is difficult to measure since an environmental or a recreational value is not an exchangeable good on the market and most of the time they are seen as a public goods. That is the reason that there is not enough collected data based on which these models can be built. That is why the first necessary step is to know the value that non-wood forest products provide in order to improve the implementation of nature recreational considerations into forest management planning (Calama et al, 2010).

Zandersen and Tol (2009), drove a meta-analysis over 26 studies from nine

European countries between 1977 and 2001. These studies are based on the travel cost method, which is a common valuation tool for assessing the value of non-marketable good and show the estimated consumer surplus per trip. The study shows that there are significant differences in recreational value between studies as they range for 0.66 € to 112 €, being the median 4.52 €. The reason for these differences is explained by the differences among the types of recreational activity, the typology of sites and the valuation methodology.

Considering the influence of the typology of the sites, Edwards et al. (2012) carried out a study based on a Delphi experts survey to know the public preferences across Europe in different forest sites regarding recreational aspects. The survey was made to obtain data of recreational value in 240 different types of forests within four regions: Central Europe, Iberia, Great Britain and the Nordic Region. The results of a conjoint analysis showed to what extent visitors prefer a degree of managed stand in contrast with unmanaged nature reserves. The phase of development of the stand was proven to contribute to the recreational value whereas the tree species type were no taken into account so much. It was proven that retention of over-grown individuals and low-impact silviculture has to be taken into account if the goal of the management is to maximize the recreational value.

Regarding different types of recreational activity some countries are making efforts to assess the value of the production of some species that, because of their traditional background or the current social interest over them are the source of a great recreational value. That is the case with mushroom and berry picking.

In Finland, a survey about values of the forest showed that biodiversity, scenic beauty, berries and mushrooms were seen as the most valuable aspects (Kangas and Niemeläinen, 1996). Given that berries picking has such a big importance, Ihalainen *et al.*, 2002 used photographs and expert opinions to make an empirical model of bilberry (*Vaccinum myrtilus*) and cowberry (*Vaccinium vitis-idaea*) yields based on site and stand characteristic predictors. One year later a model was created using field measurements from permanent plots (Ihalainen *et al.,* 2003). In Miiina et al. (2009) berry production was measured by creating a yield model that considered, among others, the effects of stand density and thinning. It made it possible to define some zones that are worthy for berries production by a stand growth simulator. Further on, Minna et al. (2010) created a model for optimizing the joint production of bilberries and timber.

In the case of mushroom production, some models have been developed to estimate the future yield (Bonet et al. 2008, 2010). Real production data has been used to include mushroom production into forest planning by the use of optimization tools. For instance, Diaz-Balteiro (2003) demonstrated how mushroom production generates incomes in *Pinus sylvestris* reforested stands, being 25 % higher than the Net Present Value obtained for timber. Moreover, he included in the model the preservation of some recreational areas.

Aldea et al. (2012) assessed the integration of mushroom production in forest management by using multi-criteria methods based on compromise programming and taking both mushroom and timber production as principal objectives. The results show that calculated income from mushroom production is about 20 % of the total timber production and suggested that is necessary to know the appropriate silvicultural treatments so as to establish the proper treatment the ensure optimal production and preservation of mushroom resources.

In recent years, some research on mushroom production has been included in forest planning through the use of an optimization tools, confirming the economic significance of this resource. Aldea (2009) demonstrated how including fungal resources in an optimization analysis of the "Pinar Grande" forest showed that they are a source of regular income over time, and contribute to 20 % of the total forest value. Similarly, Palahí et al. (2009) stated the economic importance of fungal resources in forest populations of *Pinus sylvestris* and *Pinus nigra* Arn. in Spain.

4. MATERIAL AND METHODS

4.1. Description of Study Site: “Pinar Grande” Forest

"Pinar grande" forest literally means "Big pine forest". The selection of this forest is based upon the fact that is one of the more representative examples of the success of forest management in Spain (Lucas, 1995). It is a good example of how can multipurpose forest planning can be implemented in the management being beneficial from the economical point of view and also for the state of the forest ecosystem. Its location within the Soria province is depicted in green in Figure 3.

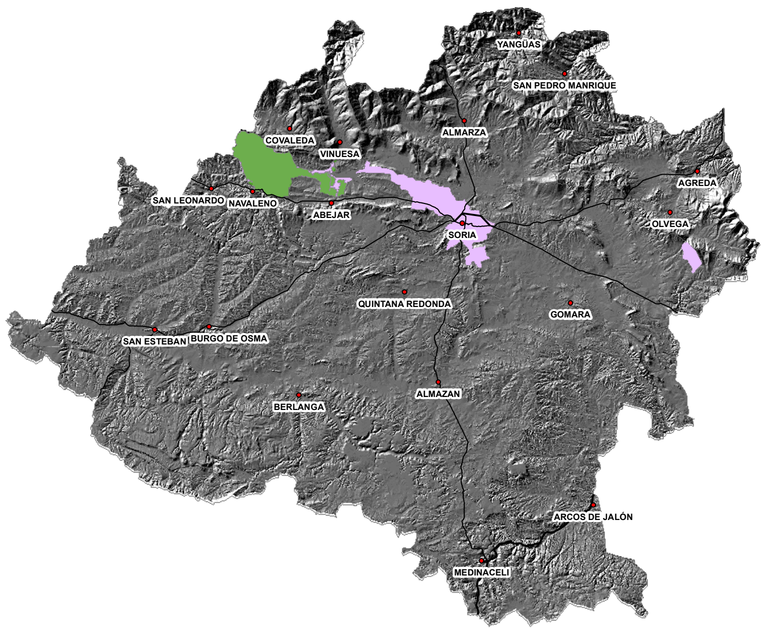

Figure 3.Location of "Pinar Grande" in Soria province

Although timber production is the main goal of the management plan, non-commercial harvesting of edible mushroom is a traditional activity in this forest with high demand. As a way to promote mushroom picking in the area and to motivate good practices for the visitors. In 2017 the managers of this forest decided to add this forest to the Mycosylva Forest Network of Mycological Parks (www.mycosylva.com). As it was previously mentioned many research about edible mushrooms has been done during the past years in this forest, and the knowledge gathered here has been the basis for creating the mycological regulation that also provides the guidelines for good practices in the whole region of *Castilla y León*.

4.1.1. Forest Management Planning and Planning Reviews

The so-called forest “Pinar grande” consist of three public forests stands (“Montes de Utilidad Pública”) (García-Serrano, 2008), which are the subject of the same Forest Management Plan and work as a Forest Management Unit:

- the forest “Monte nº 172” named “Pinar Grande” of 11,992.72 ha,
- the forest “Monte” nº 327” named “Calar y Cubillos” of 114.44 ha,
- the forest “Monte nº239” named ”Vegamblau-Sobaquillo” of 408.75 ha.

The first reference about this forest land use dates back to the 12th century (Lucas, 1995). Since then, the principal use of this land has been grazing and because of that these forest were severely damaged after several forest fires. It was caused by shepherd’s practices, overgrazing and after illegal cuts. In the beginning of the 20th century the only forests that were more or less preserved of the hazards were those from which the villagers had been receiving wood for fuel (Lucas, 2001).

In 1907, the Forest Administration decided to elaborate the first forest management plan (FMP) in “Pinar grande” forest in order to reverse the bad situation of the stand. When the first management plans were made in the Soria Region, the challenge was to switch from a overgrazing traditional practices and lack of any silvicultural knowledge to a system were grazing and timber production were compatible and all the activities were regulated to ensure both economical and ecological benefits (Lucas, 1995).

The planning goal was to achieve a high forest in an even-aged structure. In this first document the harvesting scheduling method of Periodic Block Method was established: the forest was divided in 5 sections, with 5 to 7 compartments each one. A 100 years rotation cycle was settled with a 20 years regeneration period for each age class, involving the division of each compartment into 5 cutting units or blocks. Each block contains from 2 to 4 stands. The chosen silvicultural method for ensuring regeneration was clear-cuts and shelterwood method.

In the 6th review the smallest forest were including in the planning for the first time. By that time the development of the stands had been improving considerably thanks to the fact that grazing was totally regulated and forest fires were over. After 75 years of implementation, production grew from 21 m^3 to 131 m^3 and annual possibility from 4,694 m^3 to 36,746 m^3. Apart from that success other measures conducted over the application of the several reviews of the FMP were the cause of the improvement of the forest status:

- property boundaries were properly defined and marked,
- cattle was excluded from the cutting units undergoing regeneration period,
- several tending activities were planned for the improvement of the stand quality

- a proper web of roads and path was created
- measure against forest fires and pests were adopted
- the harvesting of all commercial goods obtained from the forest was regulated and
- the forest was opened to hold some recreational services such as a camping, a restaurant or a swimming area in an Area reserved for a recreational goal (331.1 ha)

The last review of the Plan is the 9ª Review, which is valid during 15 years: since 2008 until 2022. It was conducted by a team led by Maria Jesus García Serrano, forest manager from the Environmental Territorial Service (Servicio territorial de Medio Ambiente de la Consejería de Medio Ambiente de la Junta de Castilla y León de Soria), and engineers from the “Tecnoma” environmental consulting firm (García Serrano, 2008).

4.1.2. Description of the forest

4.1.2.1. Legal considerations

The subject of this study is going to be the so-called “Monte de Utllidad Publica nº 172, Pinar Grande” (MUP, meaning Public Utility Forest). It is the biggest of the three under the same planning, covering an area of 12.533 hectares. It is a public forest whose ownership is shared in equal proportion between Soria’s city council and a municipal association of 150 villages called ”Mancomunidad de los 150 pueblos de la Tierra de Soria”. Because of being a public forest, the management is under the responsibility of the Environmental Territorial Service.

Regarding the special situations of its administrative regime, the MUP Pinar Grande is not included into any Site of Community importance (SCI) or Special Protection Areas (SPA) described in Red Natura 2000. According to the European directive 92/43/CEE from the 21 of May, 1992, for the conservation of natural habitat of wild flora and fauna they can be found eight habitats defined in such directive. The most significant of those are, *Juniperus thurifera* endemic forest, endemic oro-mediterranean heath with gorse and Galician-portuguese oak forest with *Quercus robur* and *Quercus pyrenaica.* The total surface occupied for these protected communities is 358,23 ha, and involves the 2.87 % of the total area.

The main customs and traditions in this region are the edible mushroom picking, regulated by the Decree "Decreto 130/1999" about mushroom collection in *Castilla y León*. In addition to these legal considerations many regulated Livestock trails pass through the forest

4.1.2.2. Natural considerations

Regarding geographical position: It is located inside the well-known region called "Tierra de Pinares", in the province of Soria, the easternmost province of *Castilla y Leon* autonomic region. It is surrounded by the municipalities of Regumiel de La Sierra, Duruelo de la Sierra, Covaleda, Molinos de Duero y Vinuesa in its North side; by cabrejas de Pinar and Abejar in the South side; by Cidones in the East side and by Canicosa de la Sierra and Navaleno in the West side. It is 45 km far from Soria, the capital of the province. It is 216 km far from Madrid and 460 km far from Barcelona. The forest limits can be seen in Figure 4.

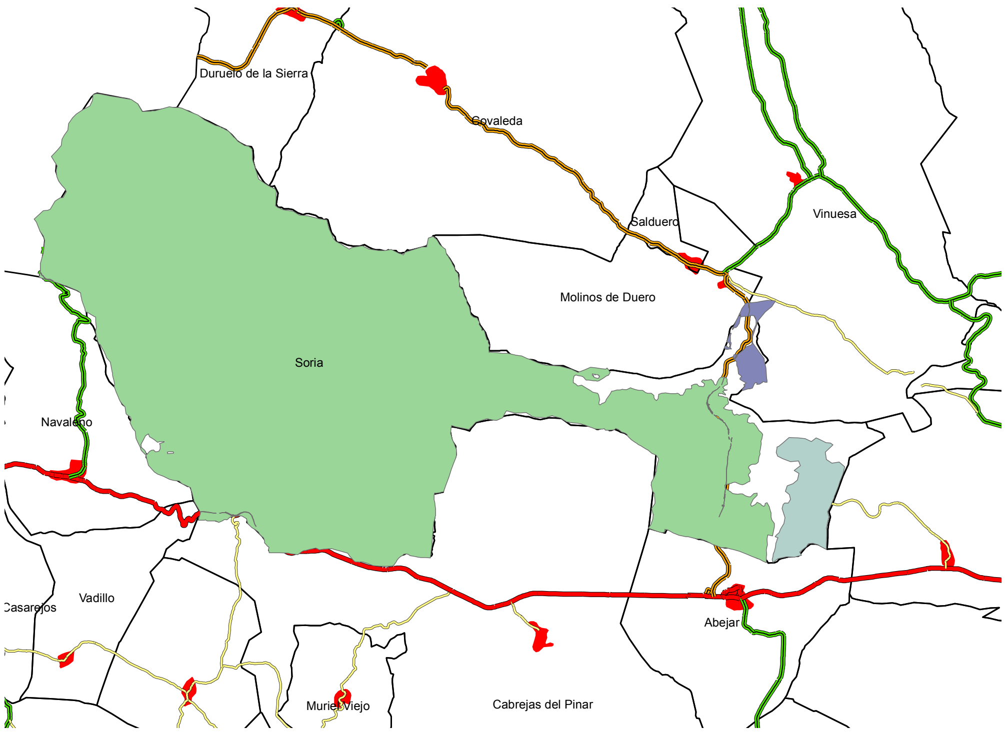

Figure 4."Pinar grande" limits and road connections

Regarding orographic position and soil characteristics Pinar Grande is located in the northern part of the "Sistema Ibérico" mountainous system ant the orography is smoothly oriented from the west side to the east side. The height variation ranges from 1,546 m a.s.l. to 1.907 m a.s.l. The north of the forest is a peaky zone belonging to the Resomo mountain range. From there, the land gradually softens tower the south, creating many dells that conform the Ebrillos river watershed .The lowest part of the land is located in the east side. This orographic configuration involves the existence of two differentiated areas where the soil characteristics are significantly different and therefore the species communities located there. The two stratums are called "cañadas" and "testeros". "Cañadas" (Trough areas) are the lowest altitudes, particularly the valley bottoms and one fourth of the slopes (less than 5% slope). Here the typical species that can be found is Scots pine (*Pinus*

sylvestris) in pure stands. The “testero” areas (hillside areas) include the three-quarters of the slopes, mostly located in the highest parts of the watershed. The species here are a mix of Scotch pine and Cluster pine (*Pinus pinaste*r). “Cañadas” occupies 1,749.6 ha and “testero” is around 10,000 ha.
Regarding soil properties, in the highest parts soil is limited for the existence of very superficial rock bed. At the mid-slope level different siliceous soils are found with a superficial layer rich in organic matter. In the lowest parts of the slopes the soil is poor in nutrients, acid and sandy-loam, partly altered for the regeneration measures.

The mean climatic features are a medium annual rainfall of 864.8 mm and a medium annual temperature of 8.8 ºC. July is the warmest month with an average temperature of 17.4 ºC. The frost period goes from November to April. The climate is mesothermic and wet (Martinez Peña, 2008).

From that total area of 12,533 hectares, 11,771 hectares correspond to continuous forest cover. Pure Scots pine stands prevail (70 % of the area), along with mixed stands of this species with Cluster pine. In some parts of the forests *Quercus pyrenaica* is present as accompanying vegetation. Some other species can be found in sparse locations such as *Populus tremula, Betula alba, Prunus avium, Quercus faginea, Quercus ilex.* In the shrubland layer the most common species are *Ilex aquifolium, Juniperus communis* L. or *Myrica gale.*
In addition, in this forest there is a great abundance of edible mushroom species, being the most consumed species the *Boletus edulis* and *Boletus pinicola*, the *Lactarius deliciosus* (L.) Gray or the *Amanita caesarea*, and with less importance *Cantharellus cibarius, Higrophorus sp.* and so on.

4.1.2.3. Socioeconomic considerations

From this section of the Forest Management Plan it is worth to highlight some aspects: The management goals for most of the cutting units are production-protection, with timber production as the principal use. Game, extensive farming and mycology are other compatible uses and there are not incompatible uses. In the 3rd block there are some units whose principal use is protection-recreational. The incomes from the regeneration cuts from 2008 to 2022 in the total area of the forest are displayed in Table 3. From the total income, 85 % is the revenue for the owners, whereas 15 % goes to the managing entity and it will be use to cover the future managing expenses. The total cost for the managers during the period is showed in Table 4. Finally, the expected Balance sheet elaborated by the managers for the period 2008-2022 is depicted in Table 5, and it shows that the improvement fund does not cover all the expenses and this forest has to receive an extra public financing effort.

Tabla 3. Expected Incomes in the period 2008-2022 in "Pinar Grande"

INCOMES 2008-2022				
Uses	**Units**	**Measurement**	**Total**	**15 % Improvement Fund**
Timber	m^3	444,717.88	13,706,694.04	2,056,004.106
Game	ha	409	858,603	128,790.45
Grazing	un	400cows/700 sheeps	28,966	4,344.9
Honeybee	un	255	9,834	1,475.1
"Playa Pita" bar	un	1	68,134	10,220.1
"Urbión" camping	un	1	391,662	58,749.3
"Las cabanas" camping	un	1	51,389	7,708.35
TOTAL			**15,115,282.00**	**2,267,292.3**

Source: García Serrano, 2008

Table 4. Expected expenses in the period 2008-2022

EXPENSES 2008-2022	
INVESTMENTS	**Total**
Defence of the property	20,540
Management monitoring	281,285
Artificial regeneration	337,222
Silvicultural measures	2,075,210
Facilities maintenance	621,410
Forest fires prevention	67,012
Conservation measures	150,000
Social use	95,114
TOTAL	**3,647,792**

Source: García Serrano, 2008

Table 5. Balance sheet for the period 2008-2022 in "Pinar Grande" forest

BALANCE SHEET 2008-2022		
Incomes	Expenses	Balance
2,267,292 €	3,647,792 €	-1,380,500 €

Source: García Serrano, 2008

Mushroom picking incomes are estimated in 0.78 €/ha according to the final profit from the mycological campaigns of 2015 and 2016. This involves an annual benefit of 9,354 €. This means only the 0,01 % of the annual value of the timber production. It can be seen that mushroom picking does not contribute significantly to the total profitability of the forest, but it is promoted for its significantly recreational value and as a source of indirect economic value for the region.

4.1.2.4. Forestry considerations

The inventory study of the forest shows that there are two main forest types: *Pinus sylvestris* and *Pinus sylvestris* mixed with *Pinus pinaster*. In each one of them the age classes are regularly distributed depending of the cutting unit they belong although in some bigger cutting areas it exist a mix of age classes in smaller stands, due to delays in regeneration or because of not having enough diameter to cut them.

The density of the stands is very variable within blocks and within age classes. *Pinus sylvestris* is the main species in the 70 % of the territory, mostly in pure stands that are located in the deep and shady sites. *Pinus pinaster* appears always mixed with Scots pine in the rest of the area, mainly in sunnier spots.

After the study of the stand height at the age of the rotation age of 100 years: 4 different site qualities were defined:

- Site quality I: found in lowest sites, protected from wind and with deeper soils: When dominant height is higher than 20 m
- Site quality II: found between the lowest and highest sites, but nearer lowest: When dominant height is from 18 to 20 m
- Site quality III: found between the lowest and highest sites, but nearer highest. When dominant height is from 15 to 28 m
- Site quality IV: found in the highest part, where soils are superficial and stony. When dominant height is smaller than 15 m

The features of the harvest planning for this forest were, as it was stated in the first review of the management: The goal of the treatment was to accomplishing an even-aged high forest. The total area was divided in 5 blocks that contain from 5 to 7 compartment each. The cutting units in each felling are subdivided as well in smaller stands.
As it was previously explained, the Harvest Scheduling method applied until the 8º review is Periodic Block Method. However, the method was shifted in this 9º review from Periodic Block Method to Single Block Method (SBM). The reason under this decision was that by the time when 9º review was implemented, blocks IV should have succeeded in their regeneration and blocks V should have started their regeneration period. However, some of the blocks had not reach the regeneration targets yet as the cuts were sometimes delayed. This situation required more flexibility in the scheduling so this SBM method was chosen for the new review.

The Single Block Method consist on creating a Regeneration Unit made from those cutting units or stand within the blocks that are more delayed in their regeneration even if they are not contiguous. The Preparation Group is created with those stands that will have to achieve regeneration in the next period. The rest of the blocks belong to the Improvement Group. Because of being more flexible this method suits better the regeneration requirements of the stand and besides, it is more useful from organizing forests with many uses in each stand (García Serrano, 2008). In Table 6 it is displayed the spatial division of the total area of the forest.

Table 6."Pinar Grande" spatial division and stands distribution

SPATIAL DIVISION					
Section	**Compartment**	**Area (ha)**	**Blocks**	**N of stands**	**Total surface**
1st	A	434.923	I-V	62	1716.391
	B	445.104			
	C	323.343			
	D	513.02			
2nd	A	291.02	I-V	85	2243.946
	B	373.827			
	C	357.651			
	D	582.906			
	E	638.361			
3rd	A	446.338	I-V	82	2370.104
	B	352.286			
	C	307.616			
	D	592.395			
	E	315.42			
	R	356.854			
4th	A	368.233	I-V	107	3097.104
	B	547.749			
	C	493.02			
	D	448.239			
	E	746.54			
	F	493.323			
5th	A	444.056	I-V	111	3040.422
	B	597.752			
	C	314.733			
	D	626.999			
	E	622			
	F	346			
	R	88.314			

Source: García Serrano, 2008

Regarding silviculture treatments, many types of regeneration cuts are performed depending on the features of each stand, and in order to succeed in achieving the natural regeneration. Clear cuttings or seed tree method are the most suitable cut regime to ensure regeneration of the stands where *Pinus pinaster* appears. However, for pure *Pinus sylvestris* stands, being a more shade tolerant species shelterwood method is a more suitable treatment.

In practice, the cuts are performed in strip shape. The process consists on carrying out three interventions within the 20 years of the regeneration period in the stands area. In each intervention one out of three strips are removed. The effect for the regeneration success within the stand equals that of the execution of the 3 shelterwood cuts in the whole area of the stand. The area of the strips is about 1,5 hectares. In the exceptional cases it never exceeds 5 hectares. The width of the strips is around 1,5 times the dominant height of the stand: 30 m for *Pinus sylvestris* trying to generate some shade in the first years and 40-45 m for *Pinus pinaster.* The length of the strip is variable and it depends on the features of the terrain. The strips are adapted to the terrain and connected with some forestry roads.

After any type of cut is prescribed to leave 4 or 5 over mature trees in order to enhance biodiversity and landscape quality. In the recreational compartments cuts are sparse in order to preserve the landscape quality are they are done by Group Selection System over trees that are over-mature or in bad conditions.

Apart from regeneration, several types of improvement cuts are prescribed. The thinning regime is designed to lead the stand into the desirable status when arriving at the end of the production cycle. The thinnings are high and selecting the best quality trees. The rotation of the thinning is 10 years with an intensity of the 30% of the basal area. This thinning regime will start when stand development has reached to pole wood (DBH>20 cm). In these stages pruning are also prescribed to reduce fire risk and improve the quality of the stems. In addition, pre-commercial thinnings are prescribed to stands in pre-thicket and thicket stage. Finally, extraordinary cuts are carried out over damaged, dead or pest-affected individuals.

4.1.3. Description of the compartment subject of study

After analyzing what would be the most appropriate area source of data, the felling area chosen for this work is the compartment B from the section 4. It has an area of 547.749 ha. It is located in the central part of the forest and corresponds to the typical trough area. The main reason for choosing this compartment is the fact that the main community is mainly pure *Pinus sylvestris* stand. In Table 7 it can be seen the allowance cut as it is calculated in the past review for both species showing that the contribution to the total is significantly higher in the case of *P. sylvestris*.

Table 7. Theoretical allowable cut of the main species in compartment 4B

Species	Annual Allowable cut	Annual Growth	TOTAL existences
	m^3/y	m^3/y	m^3
P.sylvestris	1,558.26	1,412.18	85,216.77
P.pinaster	211.19	189.28	11,654.81

Source: García Serrano, 2008

The compartment is divided in 19 stands that are also depicted in Figure 5. Two Site qualities are found in this area: In the southernmost part prevails the Site quality I whereas in the North of the compartment Site quality is IV (Table 8)

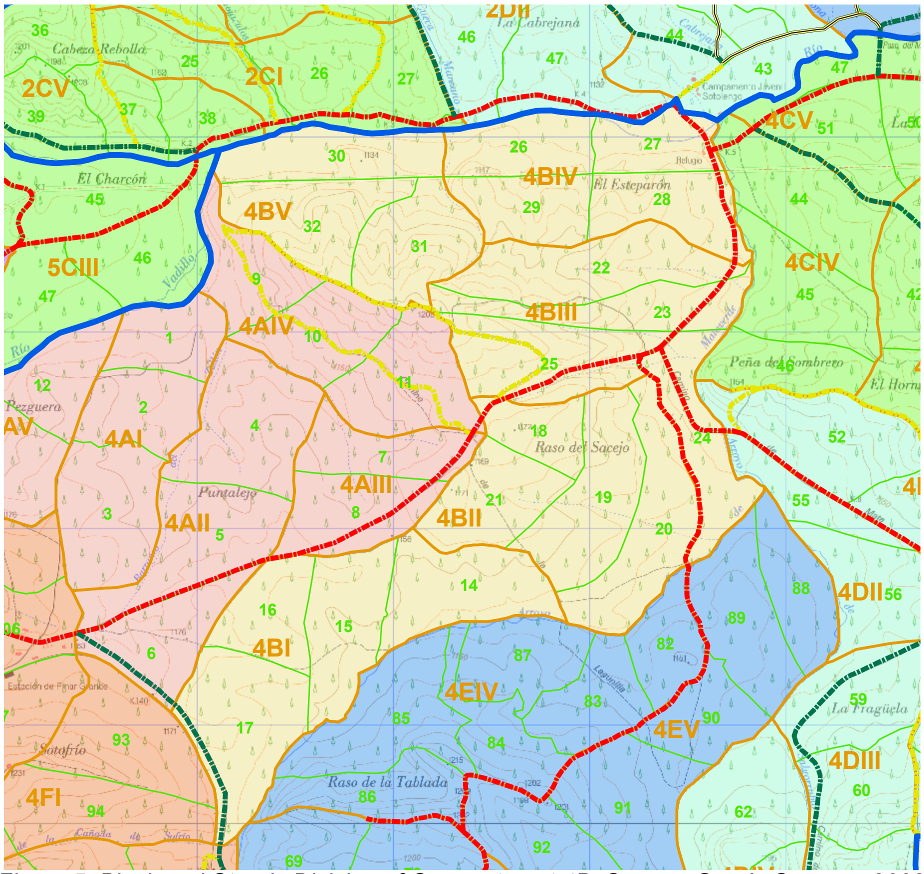

Figure 5: Block and Stands Division of Compartment 4B. Source: García Serrano, 2008

Table 8. 4B Stands Distribution by Site Quality

Site qualities	Stands
I	14,15,16,17,18,19,21
IV	20,22,23,24,25,26,27,28,29,30,31,32

Source: García Serrano, 2008

Table 9. 4B compartment Inventory Evolution through the Forest Management Plan Reviews

Inventory 4B		
Plan Review	**N/ha**	**Vol (m3)**
Original Plan	24.473	6.734
1st Rev	92.122	35.277
2nd Rev	95.252	31.358
3rd Rev	105.596	52.109
4th Rev	128.396	51.807
5th Rev	142.345	58.153
6th Rev	129.990	71.476
7th Rev	148.754	85.435
8th Rev	154.498	89.572
9th Rev	156.696	91.080

Source: García Serrano, 2008

The selection of this compartment will simplify the calculations and diminish the growth model so only 2 different are needed. Furthermore, as most of its area corresponds to a trough area, higher production is expected in comparison with hillside zones (Martínez-Peña, 2003). In Table 9 is described a summary of the inventory after each review of the FMP. The state of the Inventory over the whole planning horizon shows that both number of trees and volume have been increasing over the years Table 9.

The harvest scheduling planned for these compartments for the 9th review period involves, in accordance with the Single Block Method the aggregation of the stands within the compartment in cutting units with different destination (Table 10). The cutting plan of the regeneration cuts was settled as it is displayed in Table 11. In Table 12 it can be seen the real maximum allowance of the regeneration blocks in the compartment 4B.

Table 10. Compartment 4B Harvest Scheduling

Harvest Scheduling 4B		
Block	**Destination**	**Stands**
I	Preparation	14,15,16,17
II	Preparation	18,19,20
II	Improvement	21,
III	Improvement	22,23,24,25
IV	Improvement	26,27,28,29
V	Regeneration	30,31,32

Source: García Serrano (2008)

Table 11. Cutting plan for regeneration cut in compartment 4B

Stand	Area (ha)	Regeneration Treatment	Volume			Year	
			1st cut	2nd cut	Total	1st cut	1st cut
30	27.81	Shelterwood	3,349	3,591	6,940	2,016	-
31	27.57	Clear-cut/string	4,498	2,475	6,973	2,014	-
32	30.79	Clear-cut/string	3,050	1,680	4,730	2,015	2,020

Source: García Serrano, 2008

Table 12. Maximum allowable regeneration volume of compartment 4B

	Maximum allowable regeneration volume	
	Annual (m^3/y)	Regeneration period (m^3)
Both species	956.28	19,125.59
Pinus sylvestris	822.66	16,453.17

Source Calculated from García Serrano, 2008

Regarding economic considerations, the unitary values of the expenses is calculated from the FMP total expenses for the 15 years application period (Table 13). The expected incomes for the final cuts come from the unit values (Table 14).

Table 13. Unit expenses expected in compartment 4B

EXPENSES			
Improvements	**Total**	**cost €/ ha /year**	**cost 4B/year**
Defense of the property	20,540	0.11	60.15
Management monitoring	281,285	1.50	823.78
Artificial regeneration	337,222	1.80	987.60
Silvicultural measures	2,075,210	11.10	6,077.55
Facilities maintenance	621,410	3.32	1,819.89
Forest fires prevention	67,012	0.36	196.25
Conservation measures	150,000	0.80	439,30
Social use	95,114	0.51	278,55
TOTAL	**3,647,792**	**19.50**	**10,683.08**

Source .: García Serrano,(2008)

Table 14. Unit incomes expected in Pinar Grande in 2018

INCOMES		
Uses	**Value (€)**	**Units**
Timber	36	m^3
Mushroom	0.78	ha

Source: Lucas Santolaya, JA. 2018

4.2. Proposed Harvest Scheduling

Despite of the fact that mushroom picking is and economic and recreational valuable activity in this forest, it is a secondary use subordinated to the primary use of timber harvesting. It does not play and important role in the Planning reviews. Its economic contribution is not reflected and its social al recreational value is merely mentioned.

Therefore, in order to achieve goal of enhancing the mycological production is necessary to adapt the management that the forest is currently undergoing so that introducing mycosilviculture recommendations is meaningful and at the same time it does not interfere significantly with the primary use goals.

The proposed harvest scheduling that will be tested in this work, which is based upon following the guidelines given to encourage mushroom production, will not only serve to fulfil this task but it may also be highly beneficial in many other ways.

The basis of the proposed scheduling is maintaining the current high forest with a certain structure obtained through dividing the each stand area of even-aged sructure in a certain amount of micro-stands. These micro-stands will have a fixed size so that ecologically can match the effect that would generate applying the recommended Group Selection System to an uneven-aged stand.

The aim is to have a mosaic of holes created after regeneration cuts that are no bigger than a fixed clear-cut size and that maximum possible time surrounded by stands of the following age classes. This effect will be achieved assuming the condition that two contiguous micro-stands cannot be harvested at the same time.
Maintaining low clear-cut sizes is mainly intended to keep the source of inoculum as close as possible to the new seedlings so they will be more easily infected, minimizing the decrease in production that occurs after the removal of the tree cover.

In spite of being a different perspective, in this new approach certain number of small and non-contiguous stands will be removed to match the same allowable cut volume per year than in the traditional management. To sum up, this approach, joint to the effect of the further on designed silvicultural treatment, this spatial scheduling is supposed to add some extra help top achieve the desirable result in production.

Some of the features of the new scheduling are not going to change from the ones that the managers chose in the planning reviews because they are considered to be appropriate for the objectives of this work. The features that are not changing in the new scheduling are the following (Table 15):

Table 15.Alternatives common features

	ALTERNATIVES FEATURES
Rotation period	100 years
Minimum diameter for final cut	35 cm
Regeneration period	20 years
Tree species	*Pinus sylvestris*
Site Quality Index	I & IV

Some other features will change, making the scheduling different to the current one. For fulfilling the goals of this work, three clear-cut sizes will be tested. Each of them corresponds to different management goals. The three clear-cuts design for each alternative result in different features that are the following (Tables 16, 17 & 18):

- Alternative I:

The Alternative I (AI) corresponds to an average cut size of 0,5 ha. The shape of the cuts will be a strip with a width of 30 meters on average. This will be the desirable management method.

Table 16. Alternative I main features

	ALTERNATIVE I
Average size	0.48 ha
Maximum size	0.75 ha
Minimum size	0.31 ha
Number of cuts	**1,145**

- Alternative II:

The Alternative II (AII) corresponds to a cut size of 1,5 ha. The shape of the cuts will be also a strip with a width of 30 meters on average. The alternative would reproduce more or less the management that is currently being carried out in terms of size and shape.

Table 17. Alternative II main features

	ALTERNATIVE II
Average size	1.46 ha
Maximum size	2.02 ha
Minimum size	1.12 ha
Number of cuts	**374**

- Alternative III:

The Alternative III (AIII) corresponds to an average cut size of 5 ha. The shape of the cuts will be rectangular. The management goal would be equivalent to an intensive timber production.

Table 18.Alternative III main features

	ALTERNATIVE III
Average size	5.12 ha
Maximum size	6.78 ha
Minimum size	3.44 ha
Number of cuts	**107**

4.3.Proposed Silviculture

4.3.1.Regeneration method

The aim of the proposed silviculture is to ensure the stability and persistence of the forest. Particularly for this compartment the treatment will be adapted to those of the pure *Pinus sylvestris* stands. The type of treatment performed will be clear-cuts in strip shape. The strips will have an average width of 30 m and a length so average area is 0,5 or 1,5 ha respectively. In the alternative III the treatment applied will be clear-cuts in areas of variable width and length. Some restrictions have to be included (DGMN, 2005): In any case, from 4 to 5 trees per hectare will be kept as overgrowth trees after the last intervention. Those trees will be preferably kept in small groups not the affect the regeneration and so they are more likely to be used as microhabitats and shelter during bad climatic conditions for many animal species. In addition, about 1 to 2 trees/ha of deadwood is recommended for the same reason.
The intensity of the interventions will be different depending on the Site Quality Index of the stands. Given that in the chosen compartment there are two Site Quality Indexes in Table 17 it can be seen the desirable state of the density after the regeneration cuts where the Site quality index is I and in Table 18 where the Site quality is IV. The interventions regimes are based upon the type "1B" and "2" described in a manual for the management of *Pinus sylvestris* habitats in Castilla y León (González-Molina, 2006). Both types correspond to a model for pure and even-aged stands with primary goal of quality timber production. In particular, the type "1B" involves a model of selective thinnings in stands whose Site Quality Index is above 20 and where a high intensity of management is performed. The Type 2 corresponds to a model of selective thinnings in stands whose Site Quality Index is 20 or less than 20 and where the annual growth is higher than 2 m^3/ha/y.

4.3.2.Tending treatments

To ensure that the stands reach the rotation period in their optimal conditions according to the management goals, it is required to perform several improvement treatments during all the life of the stand.

Firstly, after the establishment of the regeneration is accomplished, it is required to carry out pre-commercial thinnings. The goal is to diminish the excessive competence that can affect the growth and they will be planned when the stands have reached pre-thicket and thicket stage.

The main feature of the tending treatment design consists on an intense regime of thinnings and the selection of between 250 and 300 plus trees. The first thinning will be systematic and low where the SQI is 20. In the best quality stands the first thinning will be low to create paths and high in the rest of the stand. At that time plus trees must be selected. Later on, the three last thinnings will be high and selective over those individual that can prevent the future development of those pre-selected plus trees. The rotation between cuts is 10 years and four interventions will be performed in total. The intensity of each intervention is about the 30% in basal area, which in practice means the removal of one or two trees per plus trees. This thinning regime will start when stand development has reached to pole wood, and that is to say that the mean quadratic diameter is higher than 20 cm.

In addition to the cuts, pruning is prescribed to promote the quality of the timber and therefore to obtain the maximum revenue after the final cut. In the best quality stands it will be scheduled the following way: the first pruning at the time of the pre-commercial thinning until 2.5 m height, and the high pruning at the time of the first thinning until 6 m height and over the plus trees. Furthermore, it is necessary to carry out extraordinary cuts, by removing the damaged, dead or pest-affected trees, in order to maintain a proper health state of the stand. In Tables 19 and 20 it is described the intensity of the tending interventions for the two Site Quality Indexes.

Table 19. Silvicultural model for site quality index >20

AGE	D(m)	Ho (m)	Treatment	Initial density (N)	Target density (N)	Thinning intensity (BA)
20-25	<9	4-6	Pre-commercial thinning and pruning	>3,000	1,800	-
30-35	12	8	-	1,800	1,800	-
40	17	10	Mix thinning and high pruning until 6 m of 250-300 plus trees	1,800	1,030	35 %
50-55	22	14	2nd selective thinning around plus trees	1,030	640	31 %
65-70	28	18	3rd selective thinning around plus trees	640	370	31 %
75-80	36	22	4th selective thinning around plus trees	370	210	31 %
80-100	>40	>24	Final cut	210	4	95 %

Source: Own elaboration based on Gonzalez-Molina (2006)

Table 20. Silvicultural model for site quality index <20

AGE	D(m)	Ho	Treatment	Initial density (N)	Target density (N)	Thinning intensity (%BA)
20-25	<9	4-6	Pre-commercial thinning and pruning	<3000		-
35-40	17	8	Low thinning with selection of 250-300 plus trees	1,800	1,100	38 %
50-55	21	11	2nd selective thinning around plus trees	1,100	700	37 %
65-70	26	14	3rd selective thinning around plus trees	700	450	37 %
75-80	31	16	4th selective thinning around plus trees	450	300	32 %
80-100	>35	>18	Final cut	300	4	95 %

Source: Own elaboration based on Gonzalez-Molina (2006)

4.4.Mathematical programming

4.4.1The optimization tool: DSS Optimal

In practice, for solving the stated problems some software is needed. DSS Optimal is a GIS based tool that allows designing different harvest scheduling based on clear cuts and shelterwood cuts (Marušák et al., 2015). The spatial restrictions are defined by adjacency constraints and the economic restrictions by harvest-flow constraints. It involves the maximization of a objective functions that represents the net present value of the harvested volume of wood, subject to those aforementioned constraints. In practice it is and ArcGis extension that consist on a GIS framework and a Solver based upon the optimization package Gurobi (Marušák et al., 2015). The tool features allow creating new harvest units according to some parameter that can be define, such as minimum and maximum area and minimum and maximum width of the plots. For the display of the result some information is required to be included in the database for each stand: area, tree species, site index, age, regeneration period and rotation age. In addition, the length and number of the planning period has to be defined. The growth model used for the construction of DSS Optimal is a yield table for *Pinus sylvestris* in Czech Republic (Černý et al., 1996)

4.4.2.The harvest scheduling model

To create the harvest scheduling model and achieve the goals stated in the introduction of this work following several steps is needed. The first action is to define the alternatives and their features. The second step is, to generate the spatial design of the cut units. The next step is to construct the mathematical model according to the structure of the Unit Restriction Model. Finally, processing the data and carrying out the optimization with the help of the DSS Optimal tool. In order to get some results as accurate as possible, it is necessary to adapt the software to the environmental conditions of the Spanish territory, particularly those that prevail in the study area. That is to say that the growing conditions are different from the ones in Czech Republic so the *Pinus sylvestris* is adapted to these conditions. This adaptation is reflected in the volume increment and therefore, for pursuing the maximum accuracy, the growth model used for developing the DSS Optimal will be changed.

4.4.3.Testing with real data

4.4.3.1. Alternatives spatial design

The spatial design of the alternatives will be created by using the ArcGIS framework and the DSS Optimal extension. It consists of dividing the area of an existing map of the forest provided by the Environmental Territorial Service of Soria. The shapefile contains the inventory of the forest and portraits the area divided in compartments, blocks and stands. The procedure continues by generating the 3 different spatial schedulings by designing the shape of the cutting plots. For the task they will be taken into consideration the restrictions regarding area and width that have been previously settled. In practice it involves generating 3 different polygon shapefiles. The procedure is to use the editing tool "polygon cut" of the DSS Optimal extension and by hand to divide de area of each stand. Once the parameters are set DSS Optimal assigns a category to each new stands that shows the user whether or not the conditions of shape and size have been fulfilled. Therefore, with the guidance of the tool the user can reshape the polygons until they meet the criteria.

4.4.3.2.Growth model

According to the site characteristics, two growth models will be related to the two site indexes. Both growth models were built for the growing conditions of the *Pinus sylvestris* in the "Sierra de Guadarrama", a mountainous range in the Northwest part of the Madrid Autonomous Community (Rojo & Montero, 1996). The reason for choosing these tables is that the silvicultural model they are currently applying in "Pinar Grande" forest is based on these tables (García Serrano, 2008; González-Molina & González-Romero, 2006). The features of each growth model can be seen in Tables 21 and 22.

Table 21. Growth model for Pinus sylvestris stands in SQI 23

Site Quality Index 23		
Age	**V(m^3/ha)**	**V increment**
20	107.3	-
40	296.6	16
60	447.8	16.1
80	540.3	11
100	596.2	6.8
120	627.9	4.1

Source: Rojo & Montero (1996)

Table 22. Growth model for Pinus sylvestris stands in SQI 20

Site Quality Index 20		
Age	**V(m^3/ha)**	**V increment**
20	101.8	-
40	250.4	13
60	378.9	13.4
80	462.6	9.4
100	514.4	6
120	544.1	3.3

Source: Rojo & Montero (1996)

4.4.3.3. Objective function

Once the harvest spatial scheduling is design for each alternative, there will be a certain number of unknown variables, each of them related to a fixed harvest unit. To each of those unknown variables is associated a coefficient, in order to create the objective function. Two objective functions are going to be maximize for each alternative:

- Harvest Flow Volume (HF): this function will associate a volume flow from each one of the unknown variables. It is composed by a volume coefficient, a surface coefficient that gives the surface of the cutting unit and the unknown integer variable associated to that cutting unit. The initial volume data is taken from the Inventory volume at 2008 (García-Serrano, 2008).

- Net Present Value (NPV): this objective function will express the economic value of the harvesting over time. It takes into account the incomes for the price of the timber in the final cut and other resources such as mushroom production and cost of the measures that the managers expend to maintain the forest. The harvesting costs are not considered in the present study as the harvesting is awarded to an enterprise that bears such costs. The Incomes and cost that are expected in the compartment "4B" can be seen in Tables 12 and 13.

Once incomes and expenses are known, the Net Present Value is calculated to homogenize the cash flow over time. The Net Present Value allows obtaining the current value of future payments and charges. To calculate it is necessary to set the interest rate.

Díaz-Balteiro (1995) explains that there are many theories about what type of discount rate should be applied in forest management, but there is not a consensus on which is the most appropriate. Despite this, all of them agree in choosing, for slow-growing species, discount rates lower than those of most private investments.

In this case, a real discount rate will be applied. It will be equal to what a long-term investment would have. The reason for using this rate comes from the fact that slow-growing species have always been considered as safe and relatively constant investments (Díaz-Balteiro, 1995). For all this, this real discount rate could be assimilated to that of the long-term public debt of the State, which is given in the form of 30-year State Obligations, and whose average interest rate as of April 9 2015 is 2.9 % (Spanish Public Treasury). Therefore, in this case it will be rounded to 3 %, taking this value as a real discount rate given the low inflation present today.

4.4.3.4. Constraints

The constraints are equation that enables the managers to include in the model all the conditioning factors that they consider important. They are considered as minimum restrictions to the management and make the model more realistic and adjusted to the constraints that managers normally include. Depending on the included restrictions, different scenarios are created and therefore the results vary as well. Although these restrictions reduce the value of the objective function, it is necessary to consider whether this reduction is compensated or not by the benefits that implies including each one of them. The structure of these equations and inequalities can be seen in Attachment I.

There are two types of restrictions: on the one hand, endogenous restrictions are those intrinsic to the model. They are essential to obtain feasible solutions to the problem under study. On the other hand, exogenous restrictions are those that are going to be settled for each specific case. The following are the ones that have been chosen for this case study:

- **Endogenous constraints**

The first restriction ensures that the decision variables are integer

- **Exogenous constraints**

First and foremost, it has to be included a constraint that ensures that each unit is only harvested once during the planning horizon.

Flow constraints: the objective functions that are maximized have to be subject to a constraint that ensures that the flows of the outputs are going to be equal in each period, so the maximization does not unbalance the product flows. In the case of the HF, the Harvest flow constraint ensures that the harvested amount is the same in each period, which at the same time is related to the balance in the cash flow. In the case of the NPV a NPV flow constraints will impose the same restriction.

Spatial constraints: the adjacency restriction ensures that two contiguous units cannot be harvested at the same time period so the maximum area restrictions are fulfilled.

4.4.4. Implementing the Alternatives

There are several steps to follow so as to prepare the data for the optimization. Firstly, to set the parameters for each alternative in the six fields: volume, regeneration period, rotation period, stand index, tree species

For the assignment of an age to the new stands the current age of the stands has to be adapted given that it is an age-class. The correspondence used is in Table 23.

Secondly, to establish the planning horizon: in this case it will be 30 years, divided in three periods of 10 years each one. The 10 years length of the planning horizon is the traditional planning horizon used in Czech Republic, where the DSS Optimal was developed (Marusak et al., 2015). Setting a period of 10 years involves that until a felled area is 10 years old and adjacent stand won't be cut. This fact ensures that each stands will be surrounded by stands at least older than 10 years old in opposite sides of the stands and at least 20 years in the other adjacent stands.

Table 23. Assigned age for the current age classes (years)

Current Age classes	Assigned Age
0-20	10
20-40	30
40-60	50
60-80	70
80-100	90

5.RESULTS

This chapter shows the results after the optimization of the three alternatives subject with the aforementioned restrictions. The imposition of flow constraints generates no feasible solutions. For that reason, for each alternative different degrees of relaxation of the flow constraints have been tested. When the HF is optimized, in addition to the harvested amount in each period, it is calculated the NPV associated. Moreover, the NPV is optimized, subject to several degrees of restriction of the NPV flow between the periods. The harvested amount is also calculated in this case.

Furthermore, the different spatial scheduling that result from the combination of the three different alternatives, the two optimized functions and the different flows is displayed in 18 maps located in Attachments II. The general features of the obtained clear-cuts distribution for each alternative are in Tables 22, 23, and 24.

5.1 Alternative I

The main features of the time scheduling obtained after the optimization of both objective functions are shown in Table 24. It is remarkable that 40 % of the cuts are gathered in the last period.

Table 24. Average time scheduling of Alternative I

	ALTERNATIVE I CLEAR-CUTS
Time distribution	**Average number of cuts**
1st period	54
2nd period	52
3rd period	71
TOTAL	**177**

Table 25 shows that the relaxation of the harvest flow is related with an increment in the total harvested amount and that is also reflected in an increment of the NPV associated. It also shows that such increment in the harvested amount lies mainly in the third period. The maximum harvested amount is related to the biggest relaxation and it is 10 % higher than the 5 %HF. The same happens with the maximum NPV.

Table 25. Results of Harvest Flow Volume optimization in Alternative I

	ALTERNATIVE I (3 % interest rate)					
	5 % harvest flow		10 % harvest flow		15 % harvest flow	
	Harvested amount (m^3)	NPV (€)	Harvested amount (m^3)	NPV (€)	Harvested amount (m^3)	NPV (€)
1st period	7,770	179,181	7,768	179,130	7,768	179,130
2nd period	8,158	140,048	8,544	146,659	8,933	153,354
3rd period	8,566	109,428	9,399	120,090	10,273	131,247
Total	**24,495**	**428,658**	**25,712**	**445,881**	**26,974**	**463,733**

As it happens to the previous, Table 26 shows that the relaxation of the flow constraint significantly affects the harvested amount, being this 10% higher in the last scenario than in the first.

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Table 26. Results of Net Present Value optimization in Alternative I

	ALTERNATIVE I (3 % interest rate)					
	5 % NPV flow		10 % NPV flow		15 % NPV flow	
	Harvested amount (m^3)	NPV	Harvested amount (m^3)	NPV	Harvested amount (m^3)	NPV
1st period	7,768	179,130	7,770	179,181	7,770	179,181
2nd period	10,958	188,086	11,481	197,099	12,002	206,056
3rd period	15,456	197,490	16,969	197,099	18,546	236,963
Total	**34,183**	**564,708**	**36,220**	**593,089**	**38,318**	**622,200**

5.2. Alternative II

The main features of the time scheduling obtained after the optimization of both objective functions are shown in Table 27. In this case, also the 39% of the cuts are in gathered in the last period.

Table 27. Average time scheduling of Alternative II

	ALTERNATIVE II CLEAR-CUTS
Time distribution	**Average number of cuts**
1st period	19
2nd period	19
3rd period	24
TOTAL	**62**

The Table 28 shows as well that the relaxation of the harvest flow is related with an increment in the total harvested amount and that such fact is reflected in an increment of the NPV associated. It also shows that such increment in the harvested amount lies mainly in the third period. The total harvested amount is 20% higher with the biggest relaxation

Table 28. Results of Harvest Flow Volume optimization in Alternative II

	ALTERNATIVE II (3 % interest rate)					
	5 % harvest flow		**10 % harvest flow**		**15 % harvest flow**	
	Harvested amount (m^3)	**NPV (€)**	**Harvested amount (m^3)**	**NPV (€)**	**Harvested amount (m^3)**	**NPV (€)**
1st period	8,517	196,503	8,715	201,073	8,715	201,073
2nd period	8,095	138,898	9,586	164,577	10,025	172,002
3rd period	8,499	108,626	10,543	134,737	11,522	147,252
Total	**25,112**	**444,029**	**28,844**	**500,388**	**30,258**	**520,328**

As it happens in the previous alternative, Table 29 shows that the relaxation of the flow constraint significantly affects the NPV, being this a 10% higher in the last scenario than in the first.

Table 29. Results of Net Present Value optimization in Alternative II

	ALTERNATIVE II (3 % interest rate)					
	5 % NPV flow		10 % NPV flow		15 % NPV flow	
	Harvested amount (m^3)	NPV	Harvested amount (m^3)	NPV	Harvested amount (m^3)	NPV
1st period	8,715	201,073	8,715	201,073	8,715	201,073
2nd period	12,298	211,122	12,884	221,164	13,470	231,228
3rd period	17,343	221,649	19,029	243,204	20,804	265,887
Total	**38,357**	**633,846**	**40,629**	**665,443**	**42,990**	**698,189**

5.3 Alternative III

The main features of the time scheduling obtained after the optimization of both objective functions are shown in Table 30. It is worth to highlight that also 40% of the cuts are also scheduled in the third period.

Table 30.Average time scheduling of Alternative III

	ALTERNATIVE III CLEAR-CUTS
Time distribution	**Average number of cuts**
1st period	7
2nd period	7
3rd period	9
TOTAL	**22**

The Table 31 shows that as in the previous alternatives, the relaxation of the harvest flow is related with an increment in the total harvested amount. It also shows that such increment in the harvested amount lies mainly in the third period. The 15% relaxation provides a raise of 10% of the harvest amount than in the first situation.

Table 31. Results of Harvest Flow Volume optimization in Alternative III

	ALTERNATIVE III (3 % interest rate)					
	5 % harvest flow		10 % harvest flow		15 % harvest flow	
	Harvested amount (m^3)	**NPV (€)**	**Harvested amount (m^3)**	**NPV (€)**	**Harvested amount (m^3)**	**NPV (€)**
1st period	9,935	229,129	9,935	225,129	9,935	229,129
2nd period	10,430	179,087	10,927	187,584	11,419	196,051
3rd period	10,947	139,878	12,012	153,462	13,132	167,746
Total	**31,313**	**548,094**	**32,875**	**570,176**	**34,487**	**592,926**

As it happens in the two previous alternatives, Table 32 shows that the relaxation of the NPV flow constraint significantly affects the NPV, being this a 10% higher in the last scenario than in the first.

Table 32.Results of Net Present Value optimization in Alternative III

	ALTERNATIVE III (3 % interest rate)					
	5 % NPV flow		10 % NPV flow		15 % NPV flow	
	Harvested amount (m^3)	**NPV (€)**	**Harvested amount (m^3)**	**NPV (€)**	**Harvested amount (m^3)**	**NPV (€)**
1st period	9,935	229,129	9,935	229,129	9,935	229,129
2nd period	14,005	240,461	14,677	252,014	15,344	263,436
3rd period	19,759	252,416	21,694	277,146	23,710	302,900
Total	**43,700**	**722,007**	**46,308**	**758,291**	**48,991**	**795,465**

6. DISCUSSION

6.1. Comparison between alternatives

Once the model is applied to the two objective functions under their respective restrictions, in this section it will be discussed the differences between the results obtained for the three designed alternatives. To begin, the analyse will focus on the value that reaches each indicator when its maximized (Figures 6 and 7). Afterwards, it will be compared the value of the harvested amount for the three alternatives when the NPV is maximized in contrast with when the HF is maximized (Figure 6). The NPV will undergo the same assessment (Figure 7).

In Figure 6 it can be seen that increasing the size of the cutting unit produces a rise in the amount of harvested timber each period. When focusing in the 5 % HF the AII results in 25,112 m^3, 2.5 % more harvested amount that the AI (24,495 m^3) whereas the value of the AIII (31,313 m^3) is 28 % higher than the AI value. Both when the HF are 10 % and 15 % the AII (28,845 m^3) generates results 12% higher than AI (25,712 m^3) whereas the AIII is 28 % higher. This assessment shows that the output values of the objective functions increase as the size of the clear-cut grows. Additionally, this pattern is repeated independently of the degree of the constraint imposition.

The influence of the harvest flow constraint is barely visible in the alternative one and it become significant in AII. In AI, when relaxing harvest flow to the 10 %,the harvested amount increases 5 %, and 10 % when it can vary a 15 %. In the case of the AII the increments raises to a difference of 14 % and 20 % respectively. In the Alternative III the difference are 4 % and 10 % so the influence of the harvest flow constraint is lower than in the second alternative.

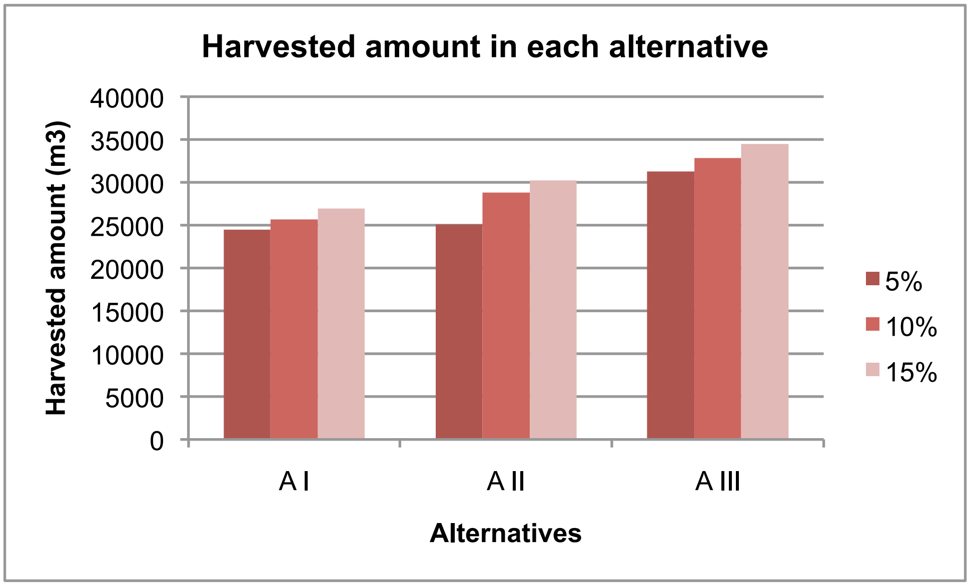

Figure 6. Total harvested amount in each alternative with different relaxation of the HF constraint

In The case of the NPV objective function, as it happens with the harvested amount, when it is maximised, for example, with a 5 % NPV flow restriction, the total NPV value increases 12 % and 28 % in AII (633,846€) and AIII (722,007 €) from the AI (564,708.00 €) (Figure 7). This assessment shows as well as in the HF analysis that the output values of the objective function increase as the size of the clear-cut grows. Additionally, this pattern is repeated independently of the degree of the constraint imposition.

The relaxation of the NPV flows generates a small increase in the values that is proportional with the percentage of the restriction. In this case all alternatives show the same pattern: when relaxing the NPV flow constraint to the 10 %, the harvested amount increases 5 %, and increases a 10 % when it can vary a 15 %.

This assessment shows as well as in the HF analysis that the output values of the objective function increase as the size of the clear-cut grows. Additionally, this pattern is repeated independently of the degree of the constraint imposition. The same happened in Kašpar et al. (2016) where was presented a spatial harvest scheduling for a commercial Eucalyptus plantation. Different sizes of the clear-cuts were tested through a maximum opening area restriction. The results showed that reducing maximum opening size would decrease NPV value but this was more or less in all the alternatives when there were not applied maximum distance constraint.

Borges et al,. (2015), after designing a spatial forest scheduling for a forest with high levels of recreational use, found that the NPV decreases 7% when including maximum area restrictions.

In spite of the economic effect of including the non-productive considerations, in this case the NPV value is not as compromised as in studies such as Bettinger et al., (2003) where it was designed a spatial forest scheduling using a heuristic technique that included adjacency restrictions in order to maintain enough amount of owl habitat next to their nesting. The results showed 24% decrease and 40% decrease in the NPV when some degree of the restrictions was included.

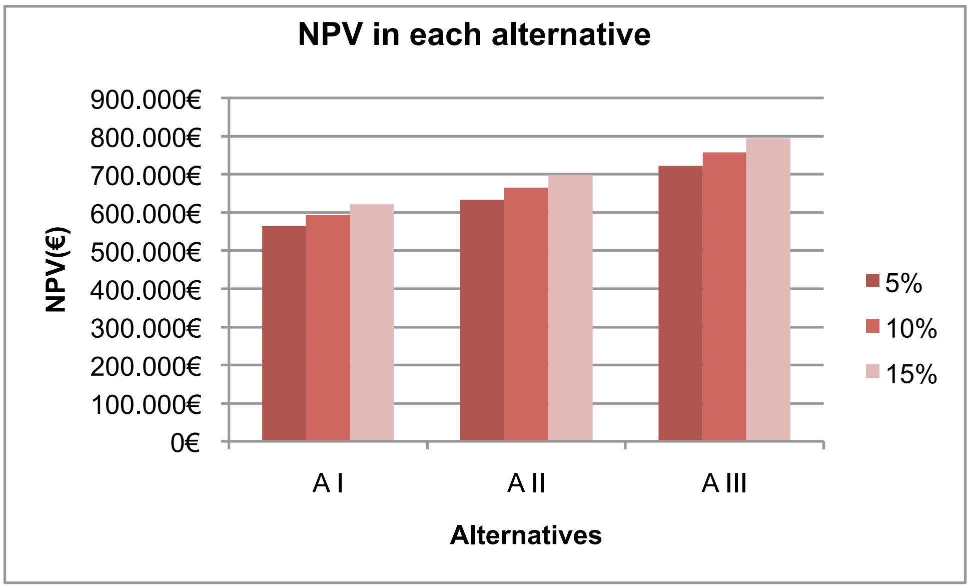

Figure 6. Total NPV in each alternative with different relaxation of the NPV flow constraint.

Finally it will be compared the harvest amount obtained by optimizing the NPV in contrast with the obtained when optimizing the HF. In the NPV case there are not restrictions in the HF, which results in a remarkable increase in the total harvested amount in all alternatives. In Figure 8 it can be seen the differences in the total harvested amount depending of the maximize variable and for each alternative and when the relaxation is 5 % HF. In AI the harvested amount is 40% higher when the NPV is optimized, and in AII and AIII is 53 % and 40 % higher, respectively. The percentages are similar to the other variations in the HF restriction

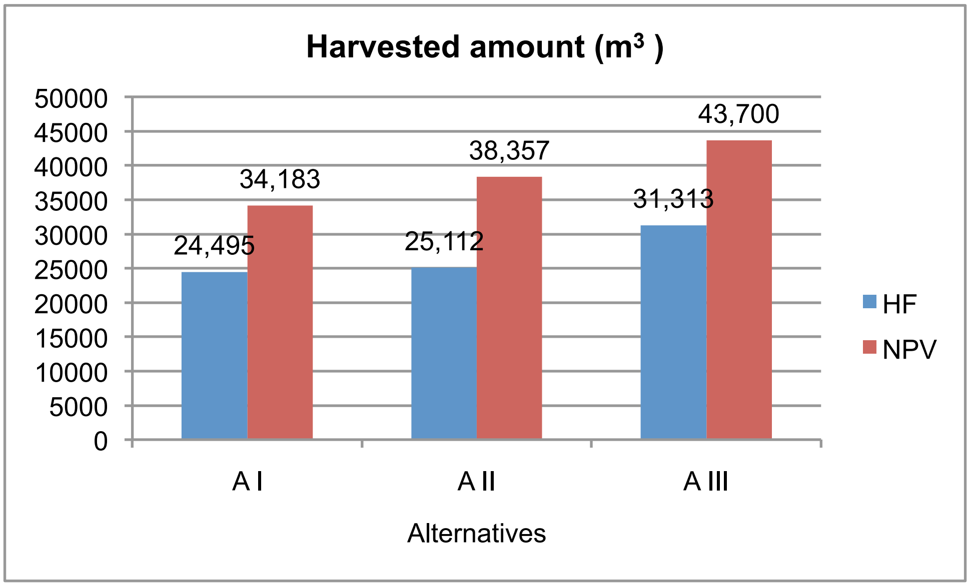

Figure 7. Total Harvested Amount (m^3) depending on the maximized objective function.

A similar analysis is done with the total NPV value. After seeing Figure 9 is obvious that optimizing the NPV generates a substantial increase in the total NPV value, even though the balance in the NPV flows may be restrictive. When the NPV flow is 5 %, the NPV is 32 % higher in AI, 43 % in AII and 32 % in AIII.

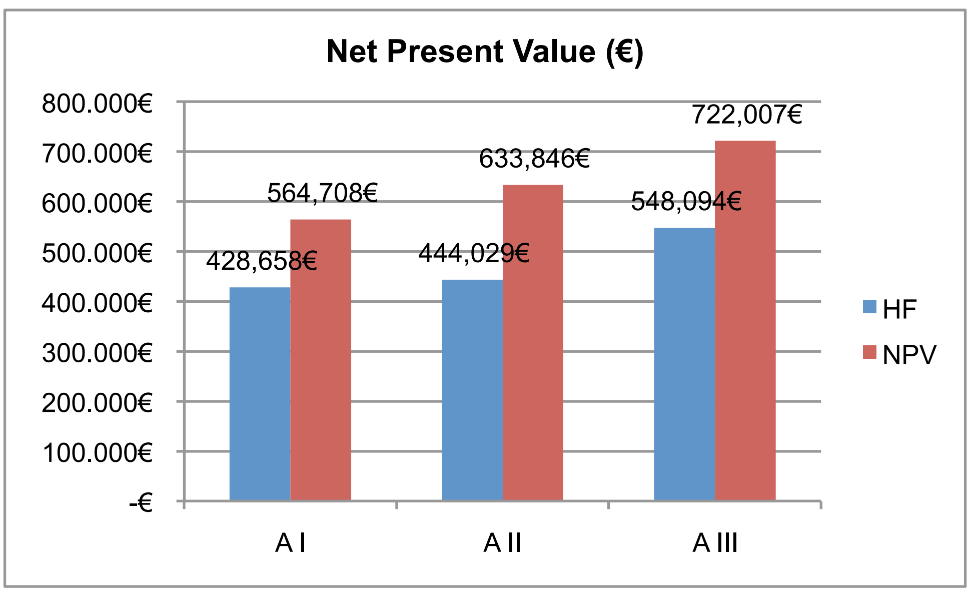

Figure 9. Total NPV (€) depending on the maximized objective function

6.2. Comparison with the current Forest Management Planning

6.2.1.Comparison of harvested volume

From the maximum regeneration allowance in the planning review it has been calculated the allowable cut of the 30 years planning horizon (Table 31). As in the planning review the value is calculated for both species, the annual allowance has been recalculated taking into account that the presence of *Pinus pinaster* is the 14 % of the *Pinus sylvestris.* After comparing with the obtained results it has to be stated that the annual regeneration allowance is calculated using the existences value of the Regeneration Blocks that in this work are the equivalent to those stands of 90 years. However if the planning horizon is 30 years, for the calculation of the allowance from the FMP, the existences and the current increment would vary as they should include the features of those stands of 70 years, which in the FMP are those in the Preparation Block. Nevertheless, the calculated allowance is an approximation that can be used to compare the obtained results and the FMP (Table 33).

Table 33. Maximum allowable regeneration volume in compartment 4B

	Maximum allowable regeneration volume		
	Annual (m^3/y)	**In regeneration period (m^3)**	**In 30 years horizon (m^3)**
Both species	956.28	19,125.59	28,688.4
Pinus sylvestris	822.66	16,453.17	**24,679.76**

Source: Calculated from García-Serrano, (2008)

After comparing this allowance with the equivalent values obtained by the model (Table 34), it can be seen that the model generates harvested amounts higher to the expected even in the Alternative I, where they are slightly higher. When optimizing the HF, the Alternative II generates 14 % more harvested amount, than the expected. It has to be pointed out that AII is the case in which, although the scheduling is different, the size of the clear-cuts equals the actual size of cuts that are being performed following the FMP (García Serrano, 2018). The Alternative III also generates harvested amounts that can reach 33 % more timber. Without the effect of the harvest flow constraint, the total harvested amount significantly rises above the 50% more volume.

Tabla 34.Comparison between obtained HF and expected HF from the FMP

	Obtained harvested amount/ harvested amount from FMP						
	Optimized HF			**Optimized NPV**			**HF FMP**
	AI	**AII**	**AIII**	**AI**	**AII**	**AIII**	
NPV (€)	25,727	28,071	32,892	36,240	40,659	46,333	**24,679.76**
% obt/FMP	104 %	114 %	133 %	147 %	165 %	188 %	

The difference may lie in the fact that the in increment used in the growth table used to run the model is not exactly the same increment used in the FMP. In the last review they chose to use the measured increment per compartment and per species (García Serrano, 2008). As a growth model they used some volume equations based of diameter and height but DSS Optimal design does not allow implementing these variable so other kind of model had to be chosen. The increments used in this study are taken from a growth table that relates the current increment with age so that they can be used in the tool. Consequently, it was used the growth model from which was constructed the recommended silvicultural system in the FM.

6.2.2.Comparison of NPV

It is difficult to establish a comparison with the NPV that is calculated in the FMP. Many variables are different. To begin, the price of timber was considered 27 €/m^3 in 2008 that was predicted to be annually growing 2 % (García Serrano, 2008). In addition, Net Present Value was calculated with a 2 % interest rate whereas in this study is the current interest rate in 2018 (3 %). Moreover, the calculation includes *Pinus Pinaster* volume. To allow some degree of comparison it will be calculated the Net Present value from the Allowable Annual regeneration volume that is defined in the FMP for the *Pinus sylvestris* in the compartment 4B (Table 32), but with the variables used in the present study. That is to say that from that annual volume NPV will be calculated from 2008 to 2038 with an interest rate 3 % and considering a fixed annual price of 36 €/m^3.

Table 35 shows that the resulted NPV values are close to the calculated NPV from the FMP. However, NPV from the FMP is calculated from an annual volume flow whereas the NPV results from a 3 period volume flow so.

Table 35.Comparison between obtained NPV and expected NPV from the FMP

	Obtained NPV/ NPV from FMP						
	Optimized HF			Optimized NPV			NPV FMP
	AI	AII	AIII	AI	AII	AIII	
NPV (€)	446,091	488,248	570,399	593,332	665,826	758,588	**592,327**
% obt/FMP	75 %	82 %	96 %	100 %	112 %	128 %	

6.3. Other alternatives. Viability of the model

After including the adjacency restrictions the obtained optimal values of the objective functions are in most cases a little higher when they are compared to the expected values of harvested timber and NPV during the settled planning horizon. This may be a positive effect of implementing the designed harvest scheduling.

However, the spatial harvest scheduling shows that not all the stands that belong to the age class 80-100 years are scheduled to be cut (Tables 32, 33 and 34). This is a practical difference compared to the traditional planning given that it will involve the gradual shift from even-aged structure to an uneven-aged structure. In practice it means that the management will be Group Selection System. This treatment is the recommended as the most suitable system for enhancing mycological production (Oria de Rueda, 2011).

As an example of the mentioned situation, in Table 36 it can be seen that the percentage of cuts that are performed in comparison to the total number of possible cuts in 90 years stands is, in the most favourable case scenario, 50% of the total. That occurs when the NPV is maximized. When the HF is maximized the harvested area barely reaches the 36 %.

Table 36. Comparison of harvested area and performed cuts is 90 years stands respect to the total in Alternative I

	ALTERNATIVE I HARVESTED AREA OF 90 YEARS STANDS						
	Harvest Amount			Net Present Value			
	5 % HF	10 % HF	15 % HF	5 % NPV	10 % NPV	15 % NPV	TOTAL
Number of cuts	64	62	62	84	89	88	**178**
Area (Ha)	32.04	31.10	31.01	42.23	44.83	44.05	**88.59**
% area/total	36 %	35 %	35 %	48 %	51 %	50 %	

In the Alternative II, the situation is slightly better (Table 37). The harvested area reaches the 60% in most cases but is still far to be suitable.

Table 37. Comparison of harvested area and performed cuts is 90 years stands respect to the total in Alternative II

	ALTERNATIVE II HARVESTED AREA OF 90 YEARS STANDS						
	Harvest Amount			Net Present Value			TOTAL
	5 % HF	10 % HF	15 % HF	5 % NPV	10 % NPV	15 % NPV	
Number of cuts	37	22	21	31	34	33	**56**
Area (Ha)	58.79	35.85	33.28	50.18	55.2	52.6	**88.59**
% area/total	66 %	40 %	38 %	57 %	62 %	59 %	

In the Alternative III (Table 3) harvested area is in most cases close to 70 % and 80%. In general it can be seen how increasing the cut sizes is accompanied by a raise in the total harvested area.

Table 38.Comparison of harvested area and performed cuts is 90 years stands respect to the total in Alternative III

	ALTERNATIVE III HARVESTED AREA OF 90 YEARS STANDS						
	Harvest Amount			Net Present Value			TOTAL
	5 % HF	10 % HF	15 % HF	5 % NPV	10 % NPV	15 % NPV	
Number of cuts	8	11	12	12	12	15	**18**
Area (Ha)	40,11	53,47	59,92	59,92	60,27	74,3	**88,59**
% area/total	45 %	60 %	68 %	68 %	68 %	84 %	

As it was mentioned above, although the NPV and harvested amount values are even over the expected, the actual even aged structure will gradually change to an uneven-aged structure.

There are several benefits of achieving the uneven-aged structure: having a continuous forest cover allows a constant biodiversity level. Additionally, the intense management that requires may generate a raise in the rural employment. The fact that the selection in made by small cut sizes ensures the regeneration of intolerant species and avoids the complications that emerge for the natural tendency of this pine forest for the even aged structure when traditional Selection System is applied (Oria de Rueda, 2008). However, maintaining this structure produces a raise in the management costs (Gonzalez Molina, 2006), and in spite of the all the positive aspect

If the managers consider that the shift to irregular structure by stands may complicate the management it may be interesting to try other models with a similar approach to this one but that generate something closer to regular or semirregular structure. Using Unit Restriction Model like in this thesis, this target could be achieved by, for instance, relaxing the conditions imposed by the adjacency constraints a certain degree (Murray and Church, 1996). However, in that case it could not be ensured that the maximum clear-cut area restrictions are going to be entirely met. Hence, in that case, Unit Restriction Model may not the best tool for implementing the designed model. Testing with Area Restriction Model may provide more feasible results for this problem as it provides more flexibility and its a more precise method, although it will be needed the help of heuristic methods for solving the problem (Murray, 1999).

6.4. Further research lines

The goal of this work is not to create a harvest scheduling that is practical, cheap and easy to implement, but to show the implications of applying a silviculture that strictly follows the indications given for enhancing mycological production.

Nevertheless, there are some aspects of the model that can be changed in the future to enhance the feasibility of a practical implementation of the obtained results.

First and foremost, the current model has been proved with a limited amount of data. Some simplifications have been made and the features of the chosen compartment are not the same for every compartment. For instance, this one was chose, among other things, for the little contribution of the *Pinus pinaster* to the total timber volume. However, in other compartments mixed stands of *Pinus sylvestris* and *Pinus pinaster* prevail, so in that case, it would be a requisite to elaborate a more complex model that includes the growth features of both species.

In addition, it would be required to improve the accuracy in the harvest scheduling. In a real situation the managers schedule annual interventions so the owners can get and steady revenue. Because of the features of the model, the output only shows which stands are going to be cut during a period length of 10 years. Therefore, it would be interesting that the model is able to display an annual distribution of the harvested stands.

Another issue that has to be addressed is the difficulty to locate the cutting stands in practice. One suggestion for a further improvement is to develop a mobile phone application, which displays the spatial harvest scheduling in the map, and allows geo-locating the cutting stands in the field.

7.CONCLUSION

In this thesis, it has been designed a spatial harvest scheduling that implements some recommended silvicultural guidelines based on the clear-cut size and its influence in the mushroom production. In addition, other alternatives have been designed based on different clear-cut sizes. An integer programming model has been built for optimizing these alternatives. The results after the optimization show that the most suitable alternative for enhancing myco-silviculture would negatively influence the structure of the age classes which although theoretically does not affect the economic output, in practice it is very likely to jeopardize the viability of the timber production. The other alternatives generate a raise in NPV and harvested amount in comparison with the defined in the FMP last review, but they involve a change from the current regular structure of the forest to an irregular structure. After analyzing the viability of the model it can be concluded that Unit Restriction Model seems to be suitable tool for assessing the effect of implementing the recommended guidelines for enhancing myco-silviculture However, if the managers intend to maintain the current even-aged structure, other models that allows more flexibility in the design of the scheduling and are more precise, such as Area Restriction Model, may generate feasible solutions more suitable for their management goals.

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9. ATTACHMENTS

ATTACHMENT I

Mathematical formulation

The objective functions and endogenous restrictions have the following expressions:

$$\max Z = \sum_{i=1}^{I} \sum_{p=1}^{P} v_{ip}.x_{ip}$$

Subject to:

$$\sum_{p=1}^{P} x_{ip} \leq 1 \quad \forall i = 1,2,...,n$$

Where

I =Number of harvest units

i = Harvest unit identifier

P = Planning horizon

p = The period

x_{ip} is a binary variable so that:

$$x_{ip} = \begin{cases} 1 \text{ if the unit } i \text{ will be harvest in period } p \\ 0 \text{ in other cases} \end{cases}$$

v_{ip} is the coefficient of the objective function, such as HF or NPV

The exogenous constraints have the following expressions:

- Flow constraints:

$$(1+\alpha)\sum_{i=1}^{I} v_{ip}\, x_{ip} \leq \sum_{i=1}^{I} v_{i(p+1)} x_{i(p+1)}\,, \forall p = 1, \dots, P$$
$$(1-\alpha)\sum_{i=1}^{I} v_{i(p-1)} x_{i(p-1)} \geq \sum_{i=1}^{I} v_{ip}\, x_{ip}, \forall p = 1, \dots, P$$

Where:

α is the fractional difference permitted in the flow level between two consequential period

- Adjacency constrains:

$$\boldsymbol{M} \cdot x \leq \boldsymbol{A}$$
$$\boldsymbol{M} = \boldsymbol{A} + \boldsymbol{B}$$

Where:

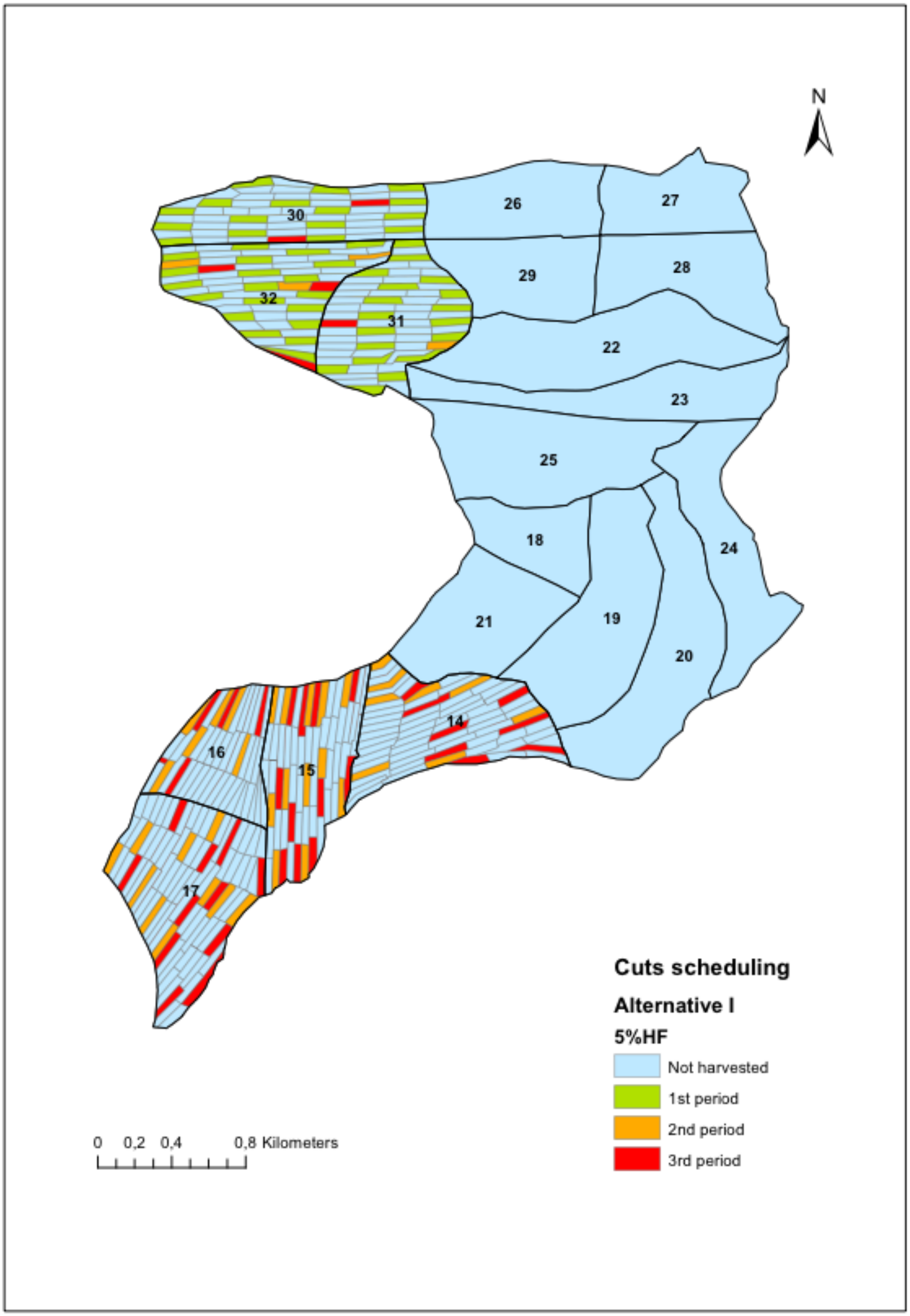
$\boldsymbol{A}$ = Adjacency matrix

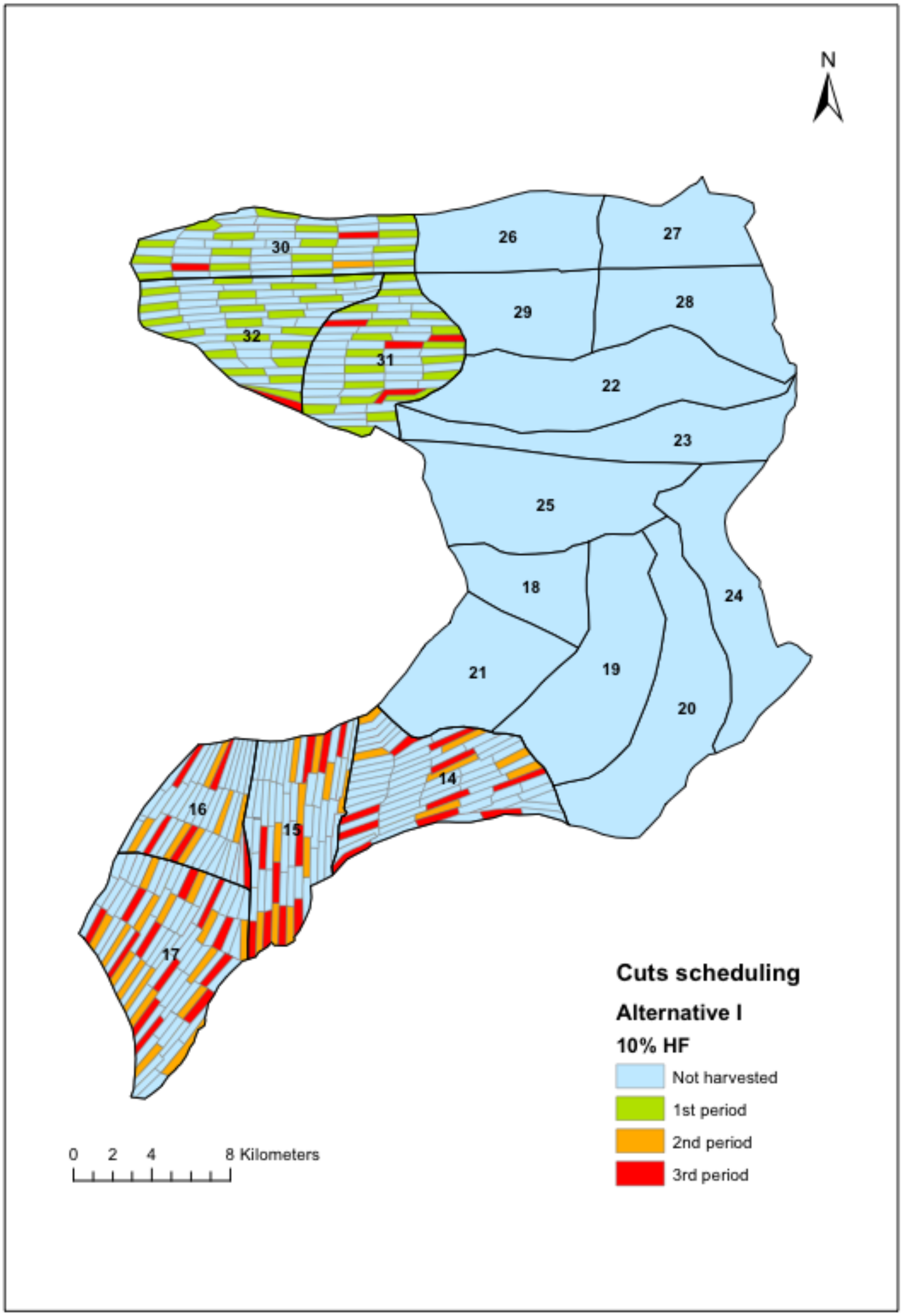
$\boldsymbol{M}$ = Modified adjacency matrix

$\boldsymbol{x}$ = Control vector

1 is an $(n \times 1)$ unit vector

ATTACHMENT II

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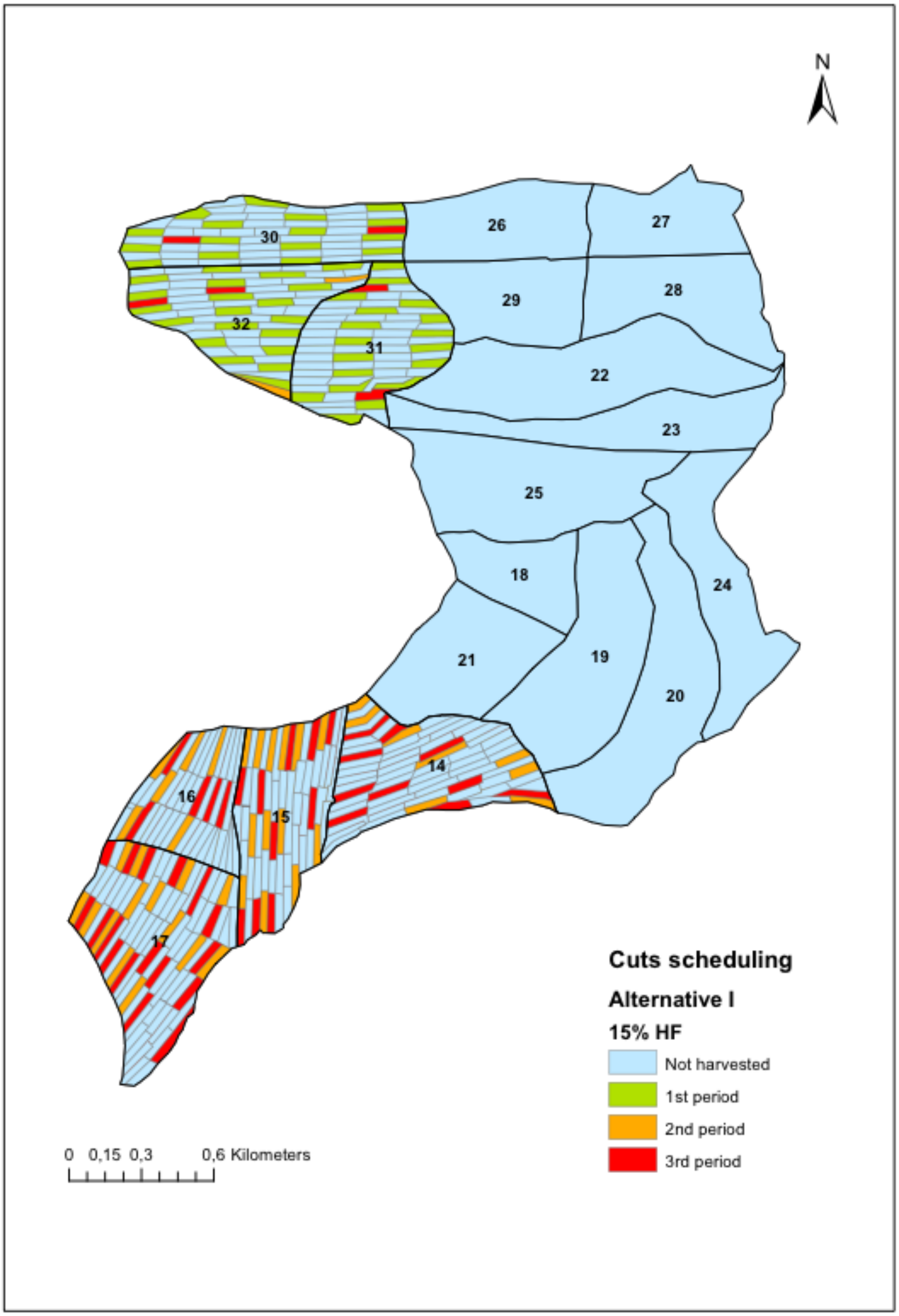
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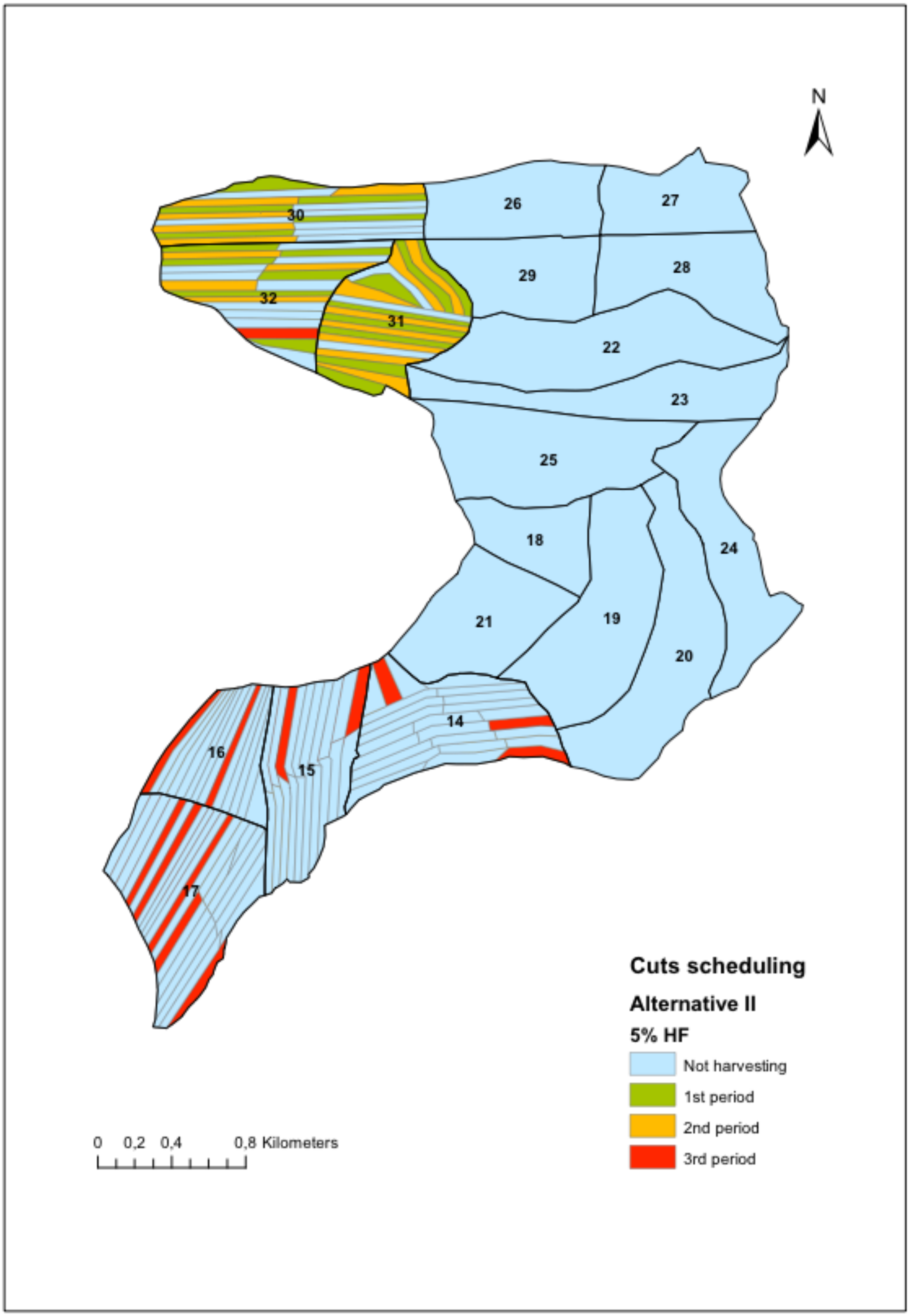
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Cuts scheduling
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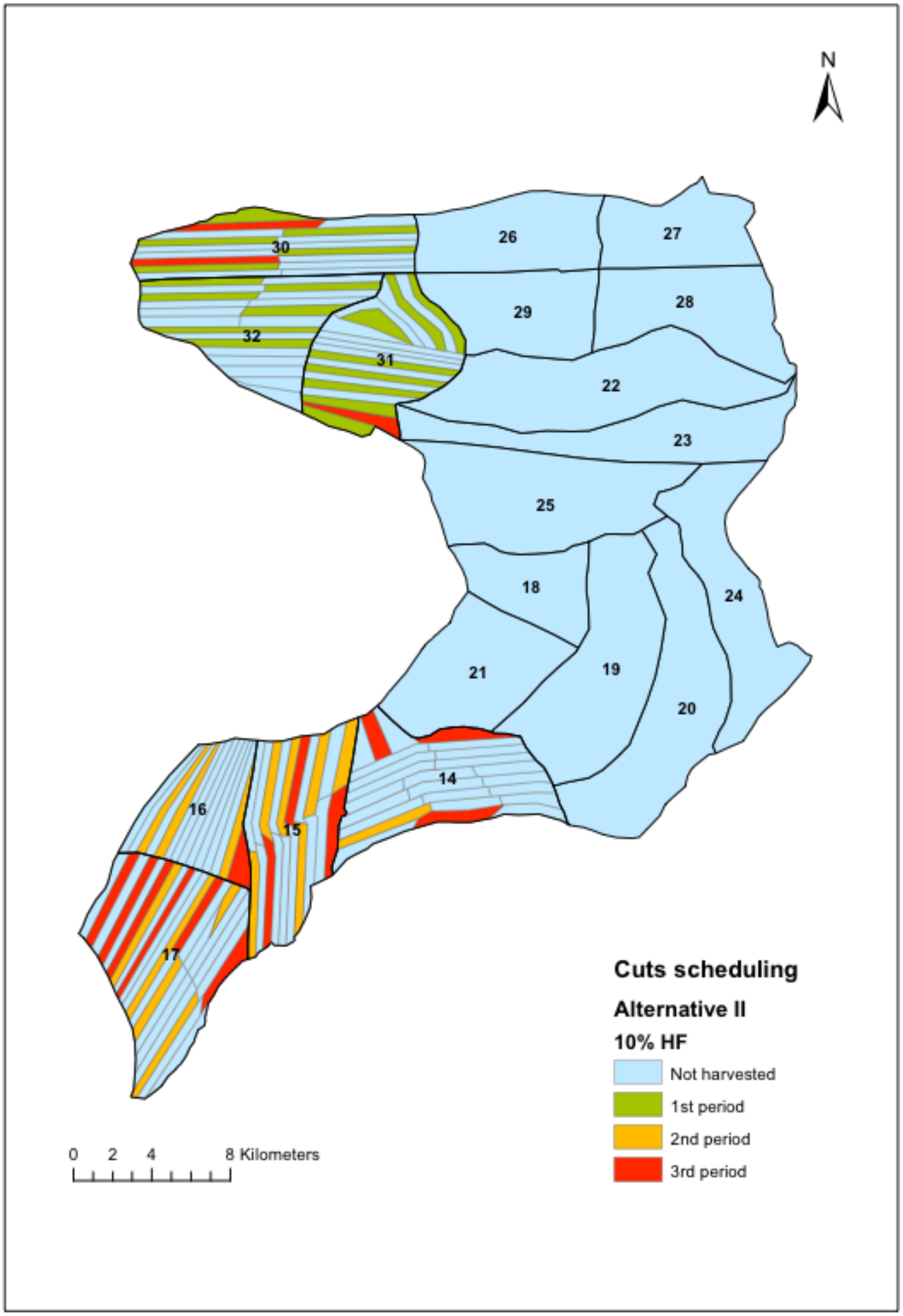
5% HF
Not harvesting
1st period
2nd period
3rd period
0 0,2 0,4 0,8 Kilometers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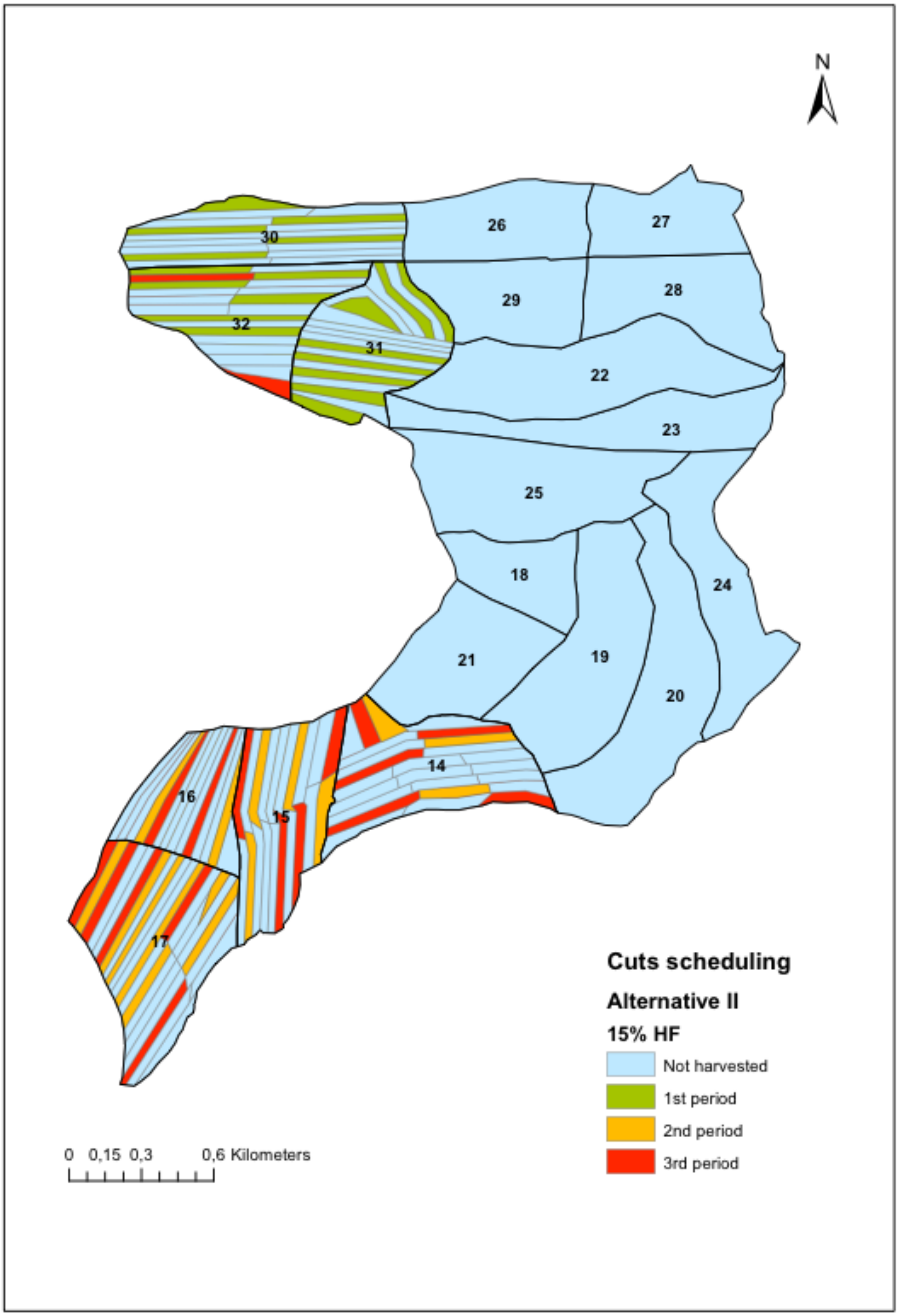
Cuts scheduling
Alternative II
10% HF
Not harvested
1st period
2nd period
3rd period
0 2 4 8 Kilometers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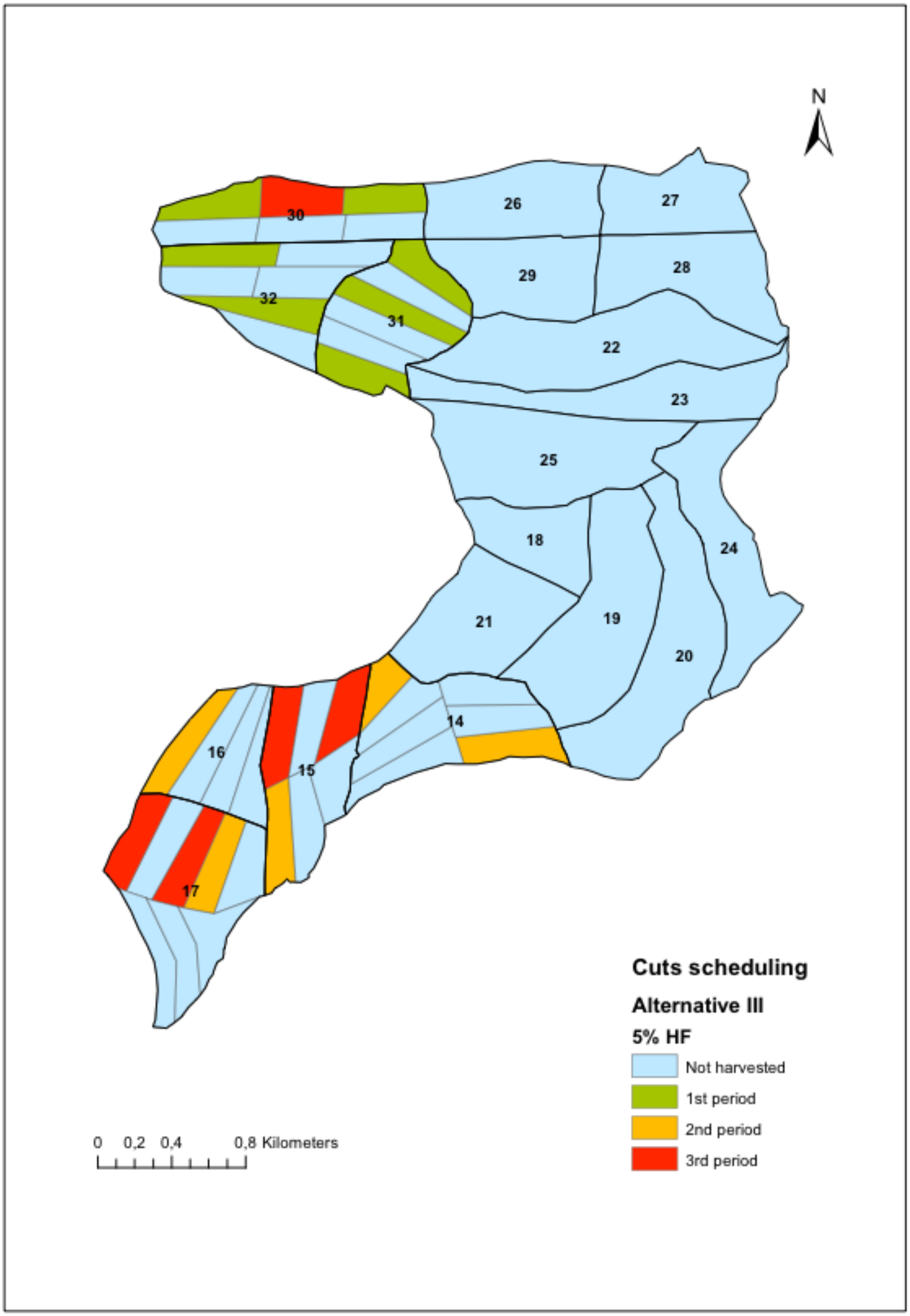
Cuts scheduling
Alternative II
15% HF
Not harvested
1st period
2nd period
3rd period
0 0,15 0,3 0,6 Kilometers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Cuts scheduling
Alternative III
5% HF
Not harvested
1st period
2nd period
3rd period
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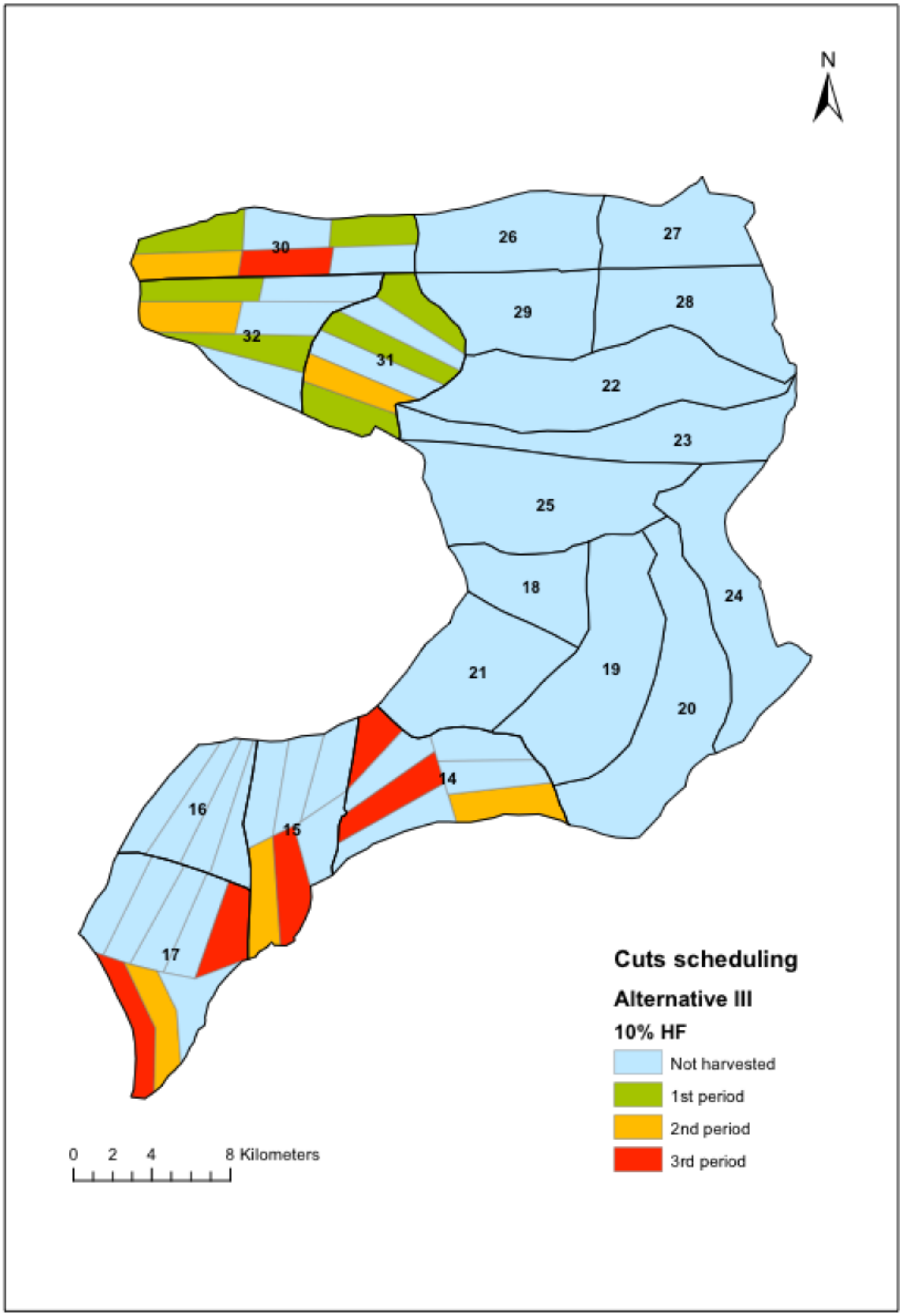
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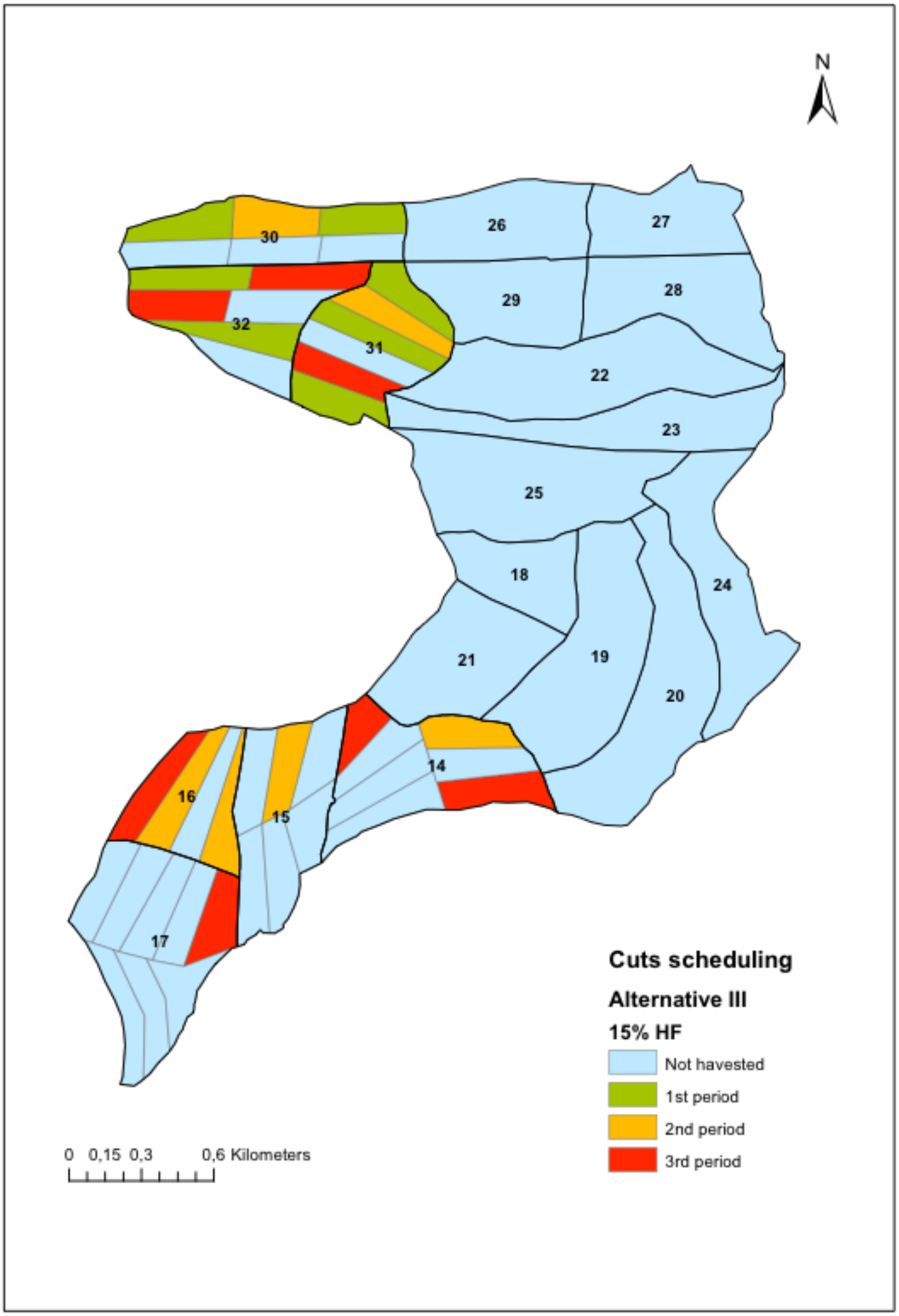
Cuts scheduling
Alternative III
10% HF
Not harvested
1st period
2nd period
3rd period
0 2 4 8 Kilometers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Cuts scheduling
Alternative III
15% HF
Not havested
1st period
2nd period
3rd period
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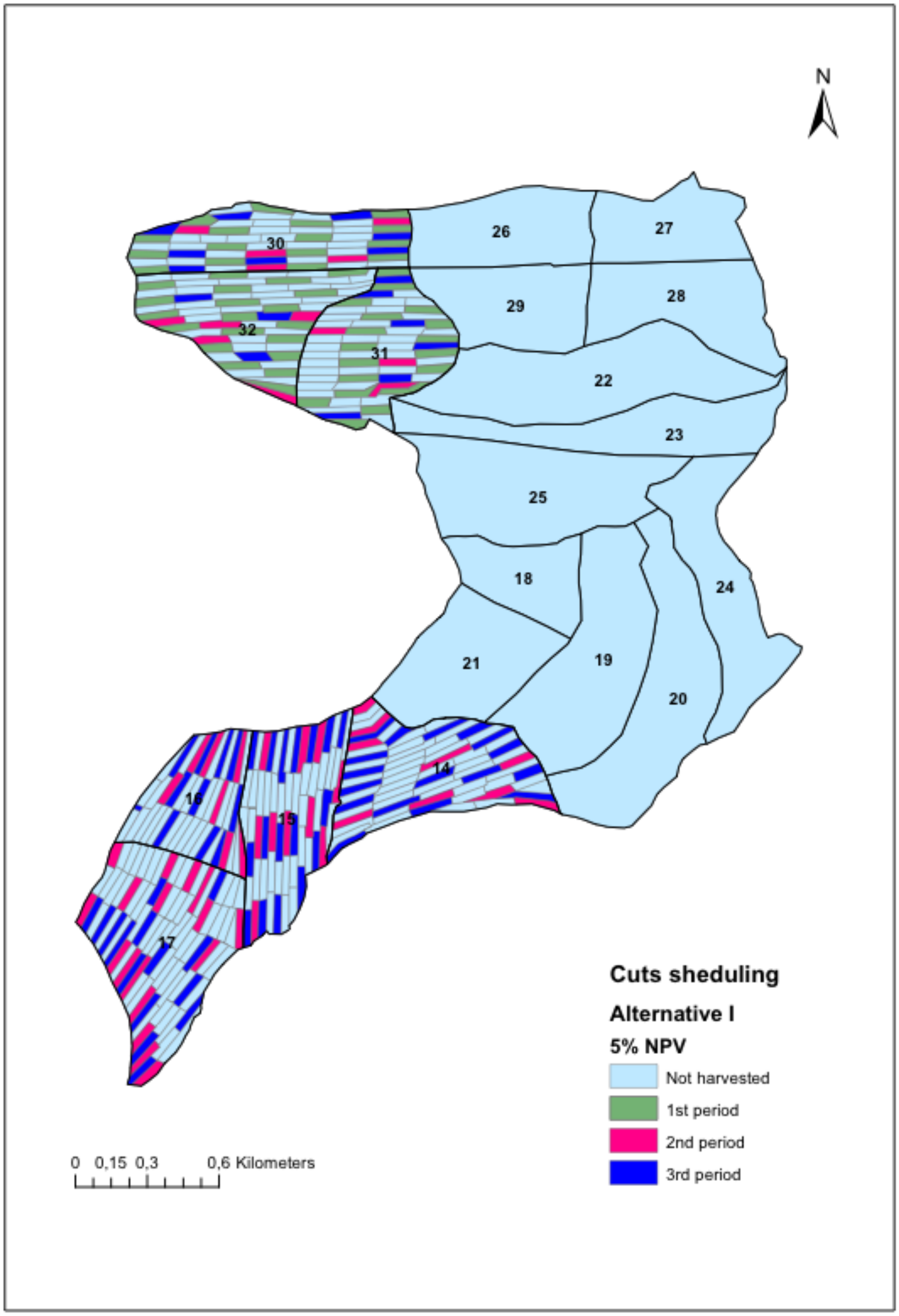
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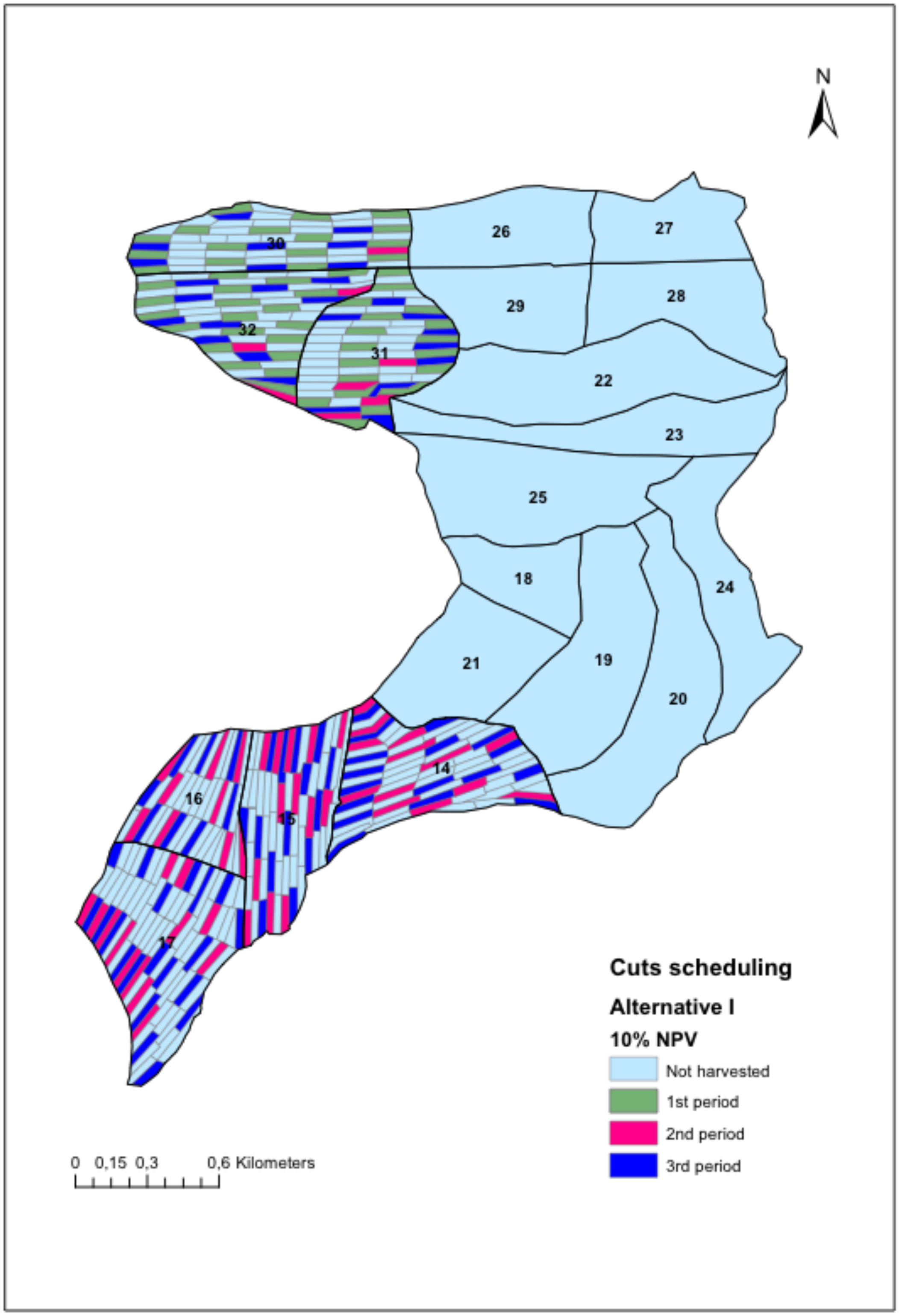
Cuts sheduling
Alternative I
5% NPV
Not harvested
1st period
2nd period
3rd period
0 0,15 0,3 0,6 Kilometers



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Cuts scheduling
Alternative I
10% NPV
Not harvested
1st period
2nd period
3rd period
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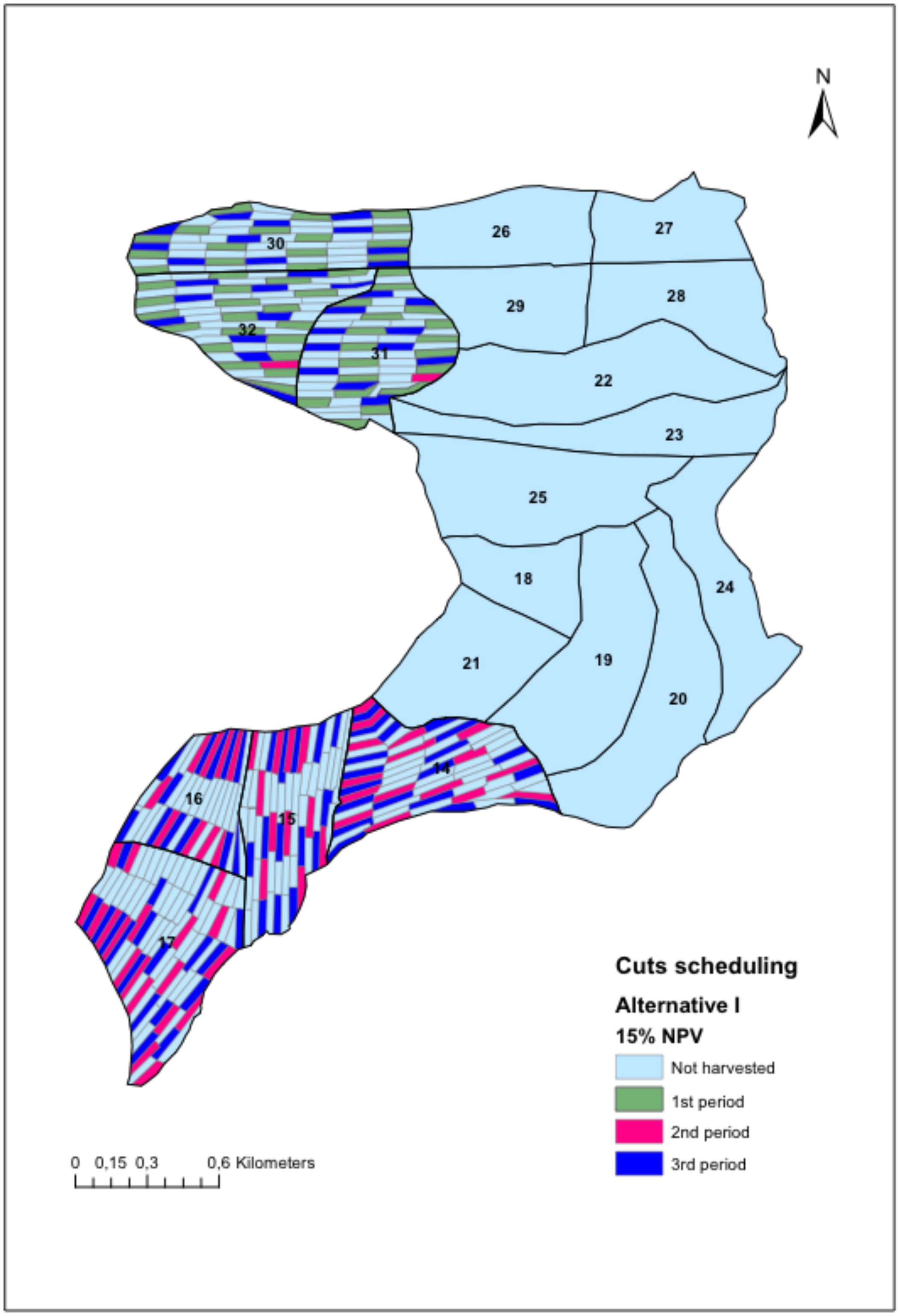
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Cuts scheduling
Alternative I
15% NPV
Not harvested
1st period
2nd period
3rd period
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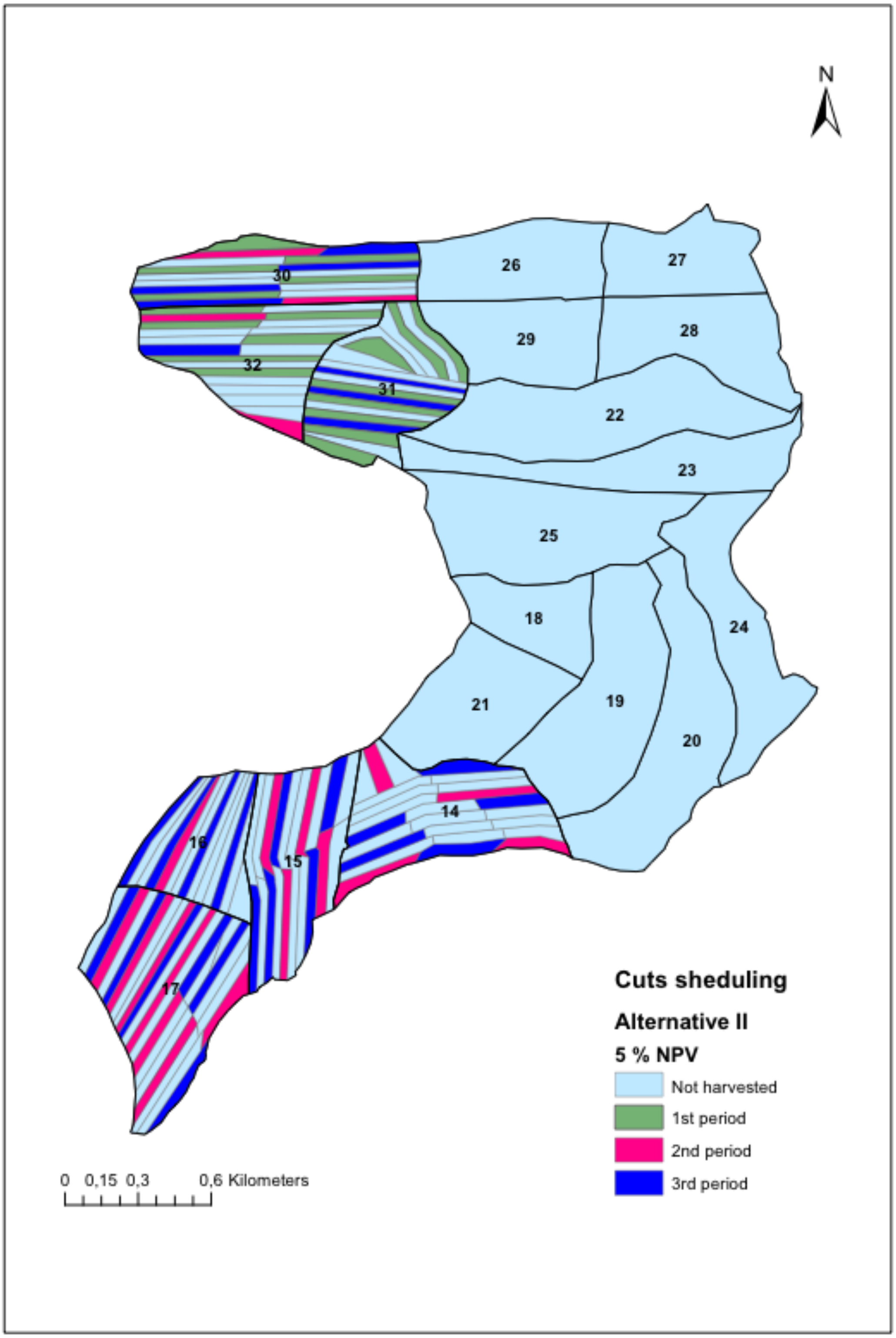
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Cuts sheduling
Alternative II
5 % NPV
Not harvested
1st period
2nd period
3rd period
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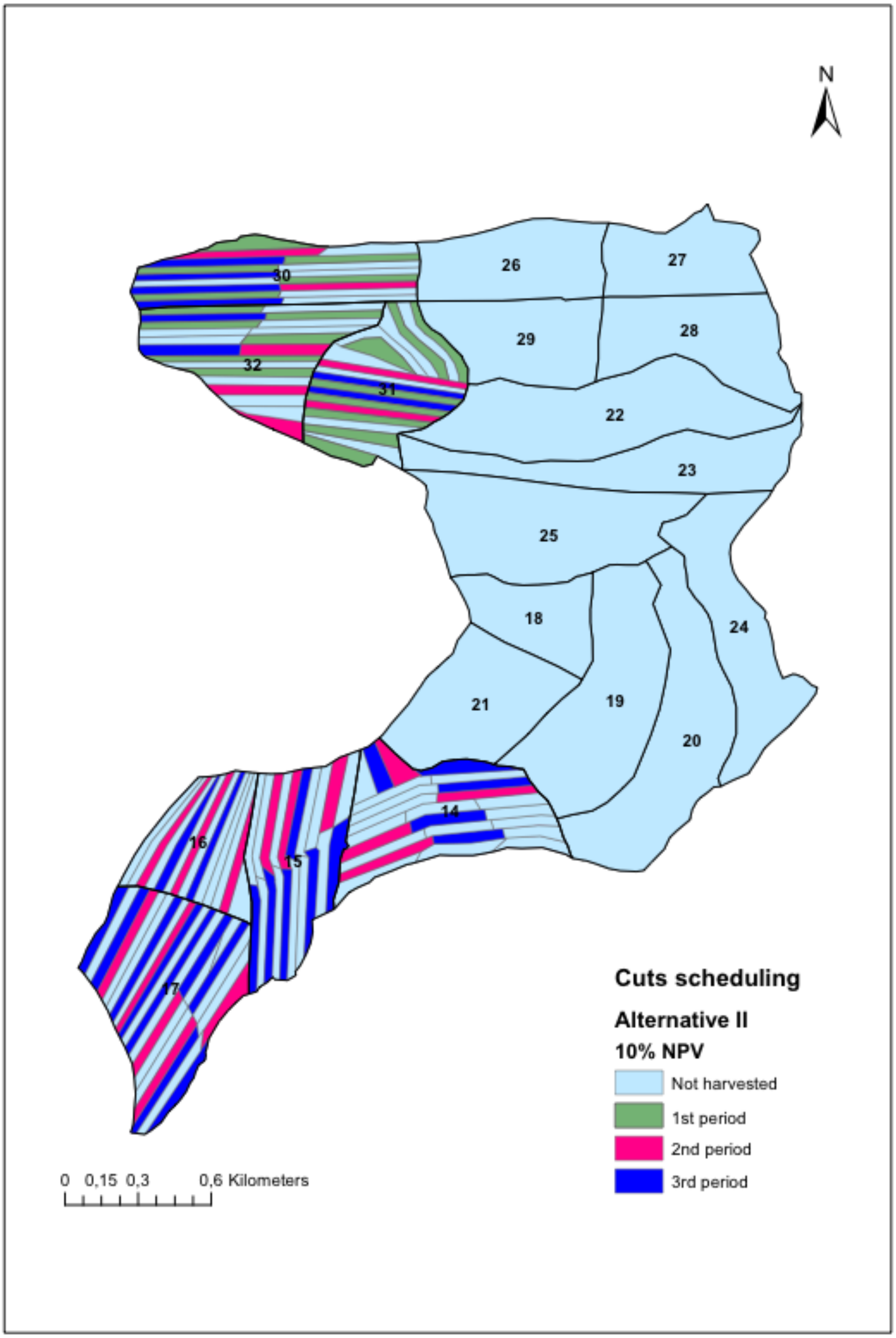
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Cuts scheduling
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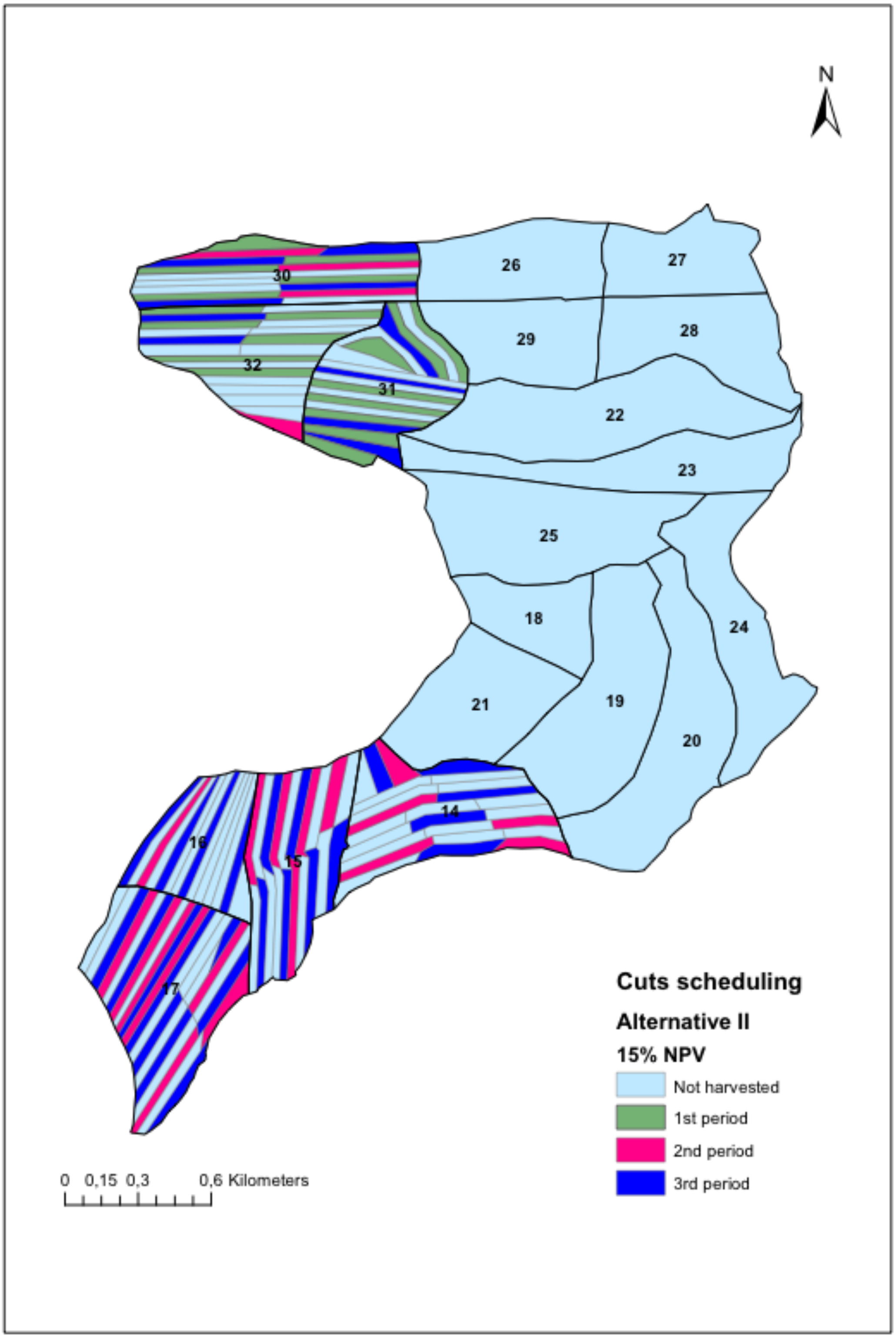
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Cuts scheduling
Alternative II
15% NPV
Not harvested
1st period
2nd period
3rd period
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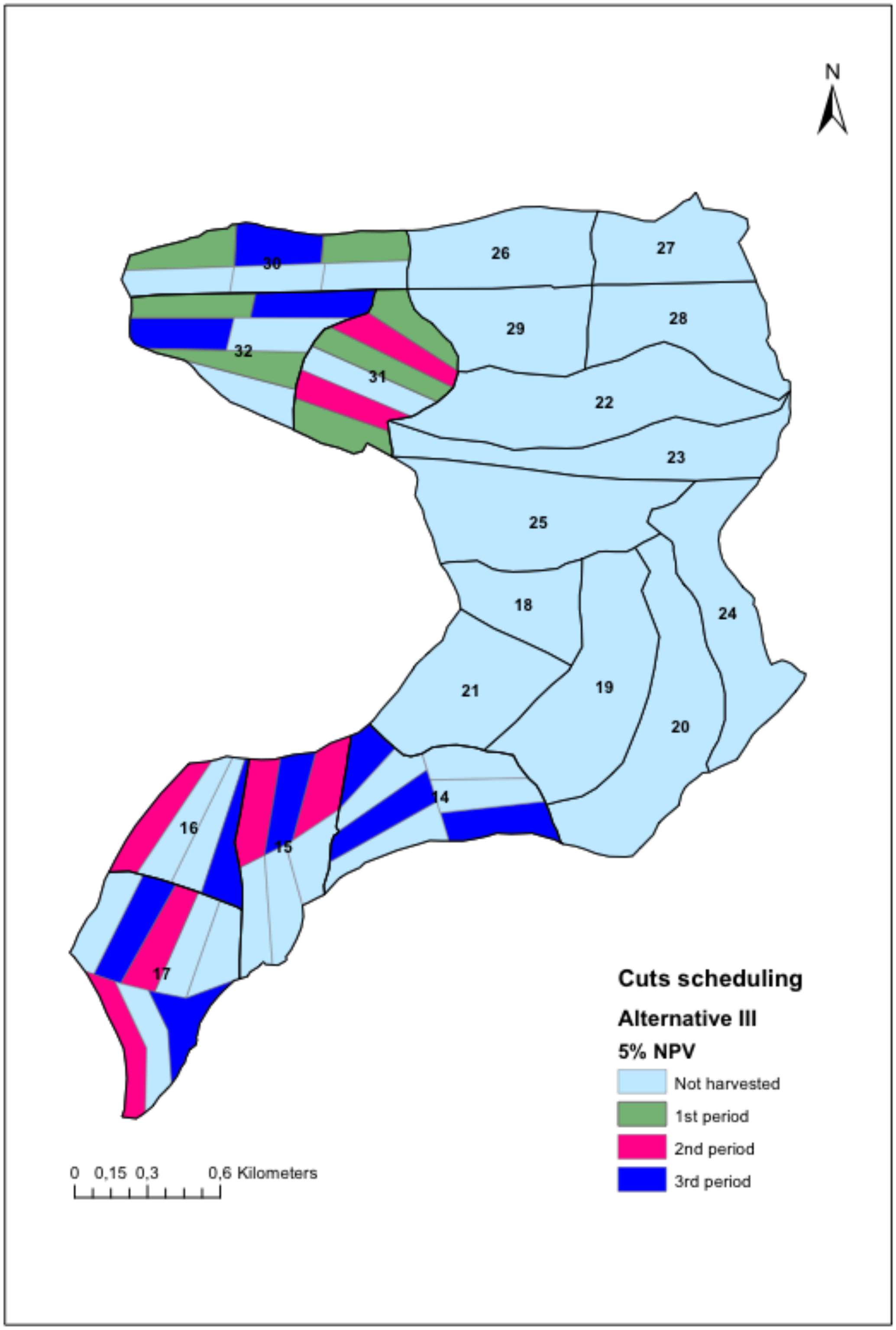
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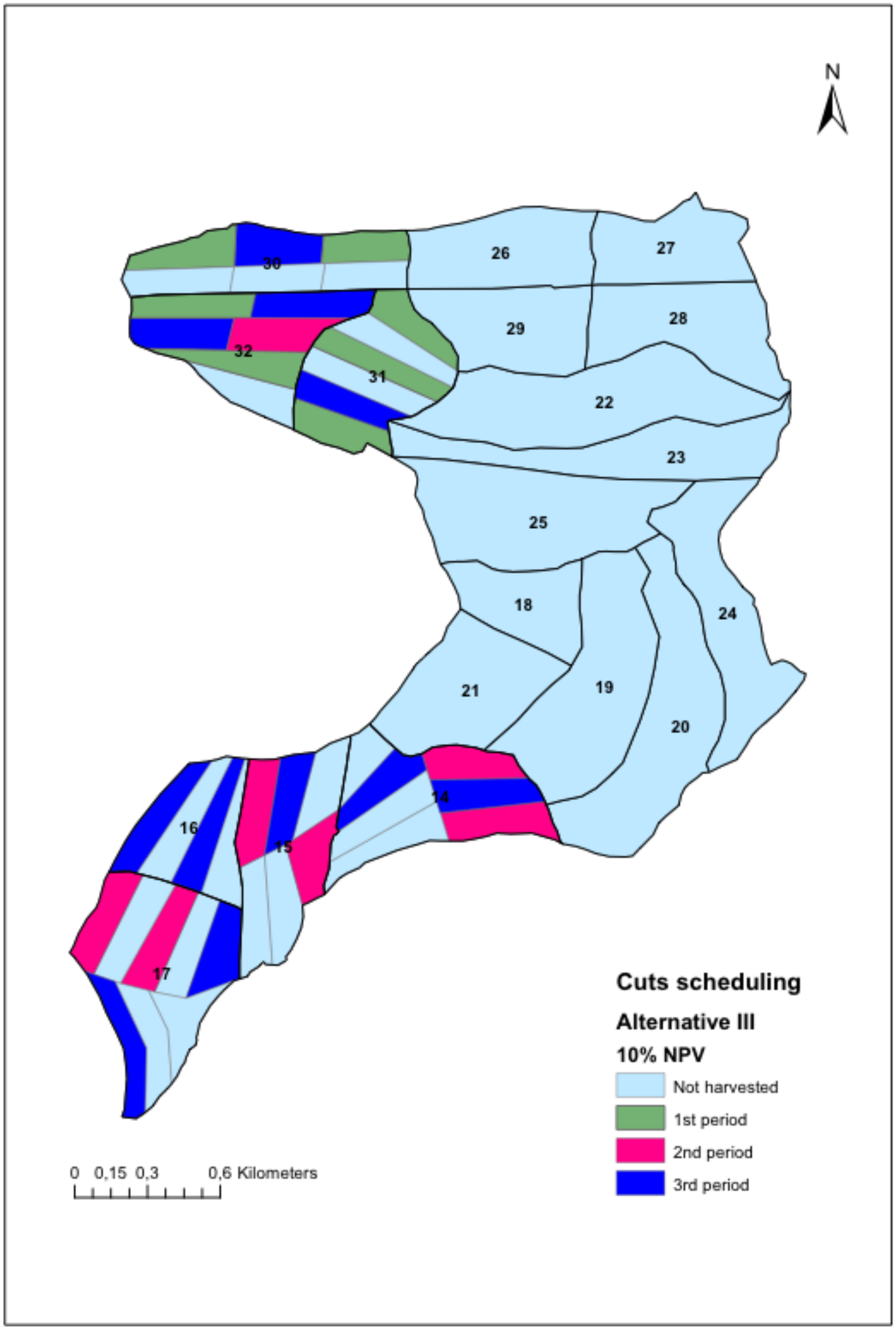
Cuts scheduling
Alternative III
5% NPV
Not harvested
1st period
2nd period
3rd period
0 0,15 0,3 0,6 Kilometers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Cuts scheduling
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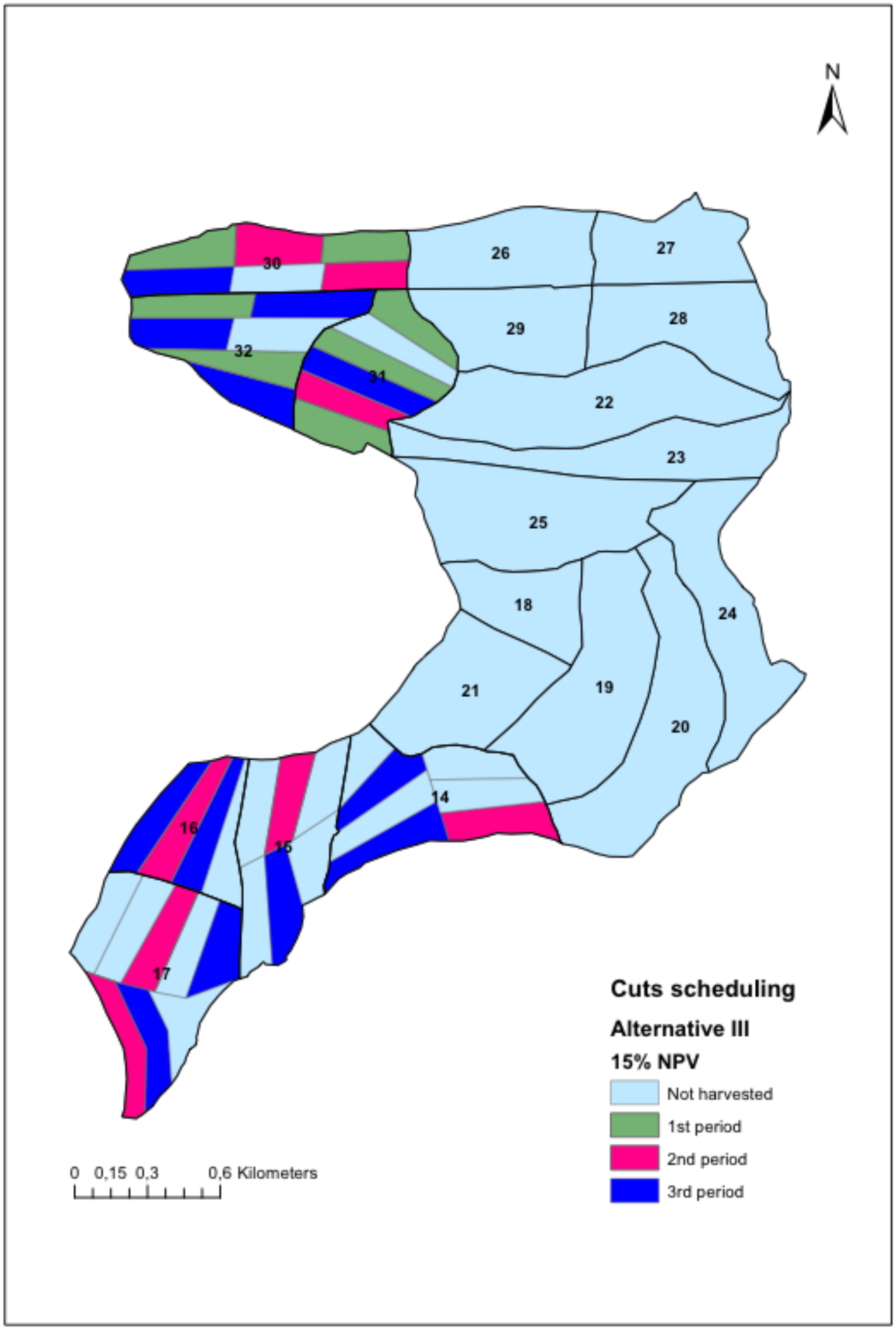
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Cuts scheduling
Alternative III
15% NPV
Not harvested
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0 0,15 0,3 0,6 Kilometers