Cork before Cattle

Quantifying Ecosystem Services in the Portuguese Montado and Questioning Ecosystem Service Mapping

Marius von Essen

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A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS
Lund University Centre for Sustainability Studies

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Submitted May 13, 2015

Supervisor: Kimberly Nicholas, LUCSUS, Lund University

Abstract

People depend on the benefits derived from nature, so called ecosystem services (ES). ES are a promising framework to evaluate ecosystems and promote conservation, but they are also difficult to measure and visualize, and the accuracy of such efforts is questionable as a basis for land management.

In this thesis, I both measured and problematized the measurement of ES. In the first part of this thesis, I used the InVEST toolkit to quantify and visualize ES for the Portuguese Montado (RQ1) and analyzed how ES provision is affected under three future scenarios: *Urbanization*, *Cattle Intensification* and *Forest Improvement* (RQ2). Results show that Montados have great potential to deliver both Provisioning (cork production) and Regulating & Maintaining (carbon storage and sequestration) services. Analyzing future LULC scenarios showed that *Forest Improvement* would result in 11.2 % more carbon storage (worth USD 2 million) and four times more cork production than *Cattle Intensification.*

In the second part, to assess the accuracy of ES mapping, I conducted a literature review (RQ3) and tested the scientific validity of the InVEST toolkit by conducting a validity analysis of InVEST (RQ4). I found that the accuracy, transparency and reliability of ES mapping is limited by a frequent reliance on proxy methods, mismatches of scale, and subjectivity of map-makers. The validity analysis of InVEST revealed that accuracy and internal validity are case-specific and dependent on data availability. Out of 31 total input variables, five have been identified as low certainty and nine as medium certainty.

Findings from the first part of this thesis suggest that decision-makers should account for ES as they contribute significantly to the landscape's value. For the Montado a traditional, forest-centered land management is likely to increase ES provision. Results from the second part illustrate that maps and ES quantification should be treated with caution, especially if the underlying processes are not disclosed. ES maps should therefore be as transparent as possible to increase their validity and credibility. Nonetheless, mapping ES, particularly when comparing future LULC scenarios, still remains a useful tool because it provides helpful information for stakeholders and decision-makers.

This thesis showed that forest-centered land management can provide higher amounts of ES while preserving the traditional character of the Montado. ES maps are a helpful tool for stakeholders to compare different land management options. However, decision-makers should be aware of the inherent drawbacks and cautious to solely base their decisions on ES maps.

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Yes, the title page states 'Marius von Essen' as author of the document. But writing this thesis would not have been possible without the help of so many people during the whole process: from sketching first applications in Lund, seeking solutions for runtime-errors in Germany, gathering shapefiles in Portugal, to asking the pettiest questions about citations formats back in Lund.

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My special thanks go to Margarida Santos-Reis, Inês Rosário, and the whole team at the University of Lisbon for making my stay in Portugal so much more fruitful and enjoyable than I could have hoped for. Without their support, my research would have been much more difficult to conduct and for sure less successful. Further, I want to thank Miguel Bugalho who took the time to explain the complex functioning of the Montado system to me.

And a big thank you to the people in the NatCap forum for finding solutions to my InVEST problems which I could not have solved otherwise.

To all my LUMATES: Huge shout-out to you for making the time in Lund so special. Without so many great people, this program would not be Jav as good as it is! Massive thanks not only to the folks who endured the sunless Lundian winters with me, but also to all my friends and companions in other places who kept in touch with me during my physical absence.

In the end, I want to thank my family for all your support, even if my journey took me farther away from home than expected – Thank you!

Strange Days: Jeder einzelne ALDI ist Beweis,
irgendetwas läuft auf eklatante Art und Weise falsch.

Sinnbild der Moderne ist geschmacksverstärktes Fleisch,
Pyrrhussiege gegen Hunger – in Plastik eingeschweißt.
Menschenpyramiden, Prezident

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Acronyms, abbreviations, and key terms

CSS	Carbon storage and sequestration
EEA	European Environmental Agency
ES	Ecosystem service(s)
GHG	Greenhouse Gas
GIS	Geographical Information System
LULC	Land-use, land-cover

Key Terms

Charneca	The study area and one of the three core areas of Companhia das Lezírias. Charneca refers to the spatial extent of the study area.
Companhia	Companhia das Lezírias, a state-owned farmstead consisting of three core areas (Lezíria Norte, Lezíria Sul, Charneca). In close collaboration with the University of Lisbon. Companhia refers to the administrative aspect of the farmstead (for spatial extent see Charneca).
Cork products	Stands for Harvested Wood Products, an additional InVEST input functioning as a fifth pool for the carbon model in order to account for carbon that is stored in cork products. For this thesis, cork is the relevant wood product.
Extensification	Increasing production by using more land area or, reversely, reducing production while maintaining the same land area.
Intensification	Increasing production with the same land area in the same location.
InVEST	A spatially explicit toolkit (free online software) developed by the Natural Capital Project that provides a suite of simulation models to quantify and map ES.
Montado	The Portuguese name for the typical Mediterranean cork oak savannahs
OPERAs	OPERAs is a project under contract from the European Commission which seeks to bridge the gap between science, policy and practice with regards to natural capital and ecosystem services. See http://www.operas-project.eu/
Raster	A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands. The carbon model requires inputs and generates outputs in raster format.

Shapefile	A vector data storage format for storing the location, shape, and attributes of geographic features. The maps used for the thesis and inputs and outputs from the timber model are shapefiles.
Vector	A coordinate-based data model that represents geographic features as points, lines and polygons. The timber model requires inputs and generates outputs in vector format.

1. Introduction

1.1. Study Context: Humanity's Greatest Challenge

Human activities degrade the environment at a pace and scale that threatens our geological epoch, the Holocene, triggering a transition towards a new epoch: the Anthropocene (Crutzen, 2002). This transition is likely to have negative impacts on ecosystem services (ES) which heavily depend on the functioning of the Earth's systems. Thus, ongoing resource depletion and habitat destruction are the greatest challenges humanity has ever faced, because a failure of the Earth's systems entails unpredictable consequences for nature and humanity (Mace, Norris, & Fitter, 2012, p. 21). ES are vital to our contemporary societies (Daily, 1997) as they describe three categories of Regulating, Provisioning & Maintenance and Cultural services that humans derive from ecosystems (Haines-Young & Potschin, 2013). ES have gained increasing attention during the past decades and are now embedded within academia, policy and decision-making (Gómez-Baggethun, de Groot, Lomas, & Montes, 2010). Further, ES have the potential to "highlight[] human dependence on ecosystems and explicitly connect[] science and society" (Jax et al., 2013, p. 266). The ES concept emerged from conservation science and introduces an economic and anthropocentric perspective by valuing and quantifying the services obtained by humans (Kosoy & Corbera, 2010). This utilitarian viewpoint (Goulder & Kennedy, 1997) is a development from previous conservation techniques which failed to put a halt to the degradation of the planet's ecosystems (Millennium Ecosystem Assessment, 2005a).

1.2. Research Area: Operationalizing Ecosystem Services

This thesis is conducted in collaboration with the Montado exemplar of the European research project Operational Potential of Ecosystem Research Applications (OPERAs) which is devoted to identifying ES across European landscapes and seeks for options to implement these in practice (OPERAs, 2015). Montado is the Portuguese name for the traditional agro-silvopastoral landscape in the Mediterranean basin (see Chapter 3.2). Considered as a biodiversity hotspot (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000) and subject to natural and anthropogenic pressures (Pinto-Correia, Ribeiro, & Sá-Sousa, 2011), the Montado is an ideal case for ES research because it exemplifies the interconnectedness of human and natural systems while providing benefits for society.

In order to transition from a theoretical to a practical concept, the UN Environmental Program suggests a tiered approach of recognizing, demonstrating and capturing the value of ES (TEEB, 2010). Demonstrating these values by visualizing and quantifying them is a central aspect as it provides stakeholders and decision-makers with tangible information in a ubiquitous units. Thereby, ES can be incorporated in decision-making and for landscape planning. In this thesis I operationalize the ES service concept by using an ES scenario mapping tool called InVEST[1] – a spatially explicit suite of software models to quantify and map ES (Sharp et al., 2014, see Chapter 2.2.1).

With the first part of this thesis I address the main sections of the ES concept as defined by the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2013). I employ one InVEST model for one final ES from each section: the Managed Timber Production model for Provisioning services, the Carbon Storage and Sequestration model for Regulating & Maintenance services, and the Recreation and Tourism model for Cultural services. Furthermore, I use InVEST to compare ES provision under three future scenarios which represent different land-use options.

Although limitations of ES mapping are known, quantitative information on how these limitations affect results is surprisingly scarce. As of 2015, only a small number of papers have been published investigating the magnitude of discrepancies between ES valuation based on primary data and ES valuation using proxies or secondary data. The same holds true for how different mapping tools and their results compare against each other. Thus, in the second part of my thesis, I review the existing literature to analyze the advantages and disadvantages as well as the accuracy of ES maps in general. Furthermore, I assess the internal validity of InVEST by examining the internal structure of two models and report about my user experiences.

1.3. Thesis Focus and Research Questions

With this thesis I want to answer one overarching research question (RQ) which is further divided into two broader research themes (RT-Mapping and RT-Validity), each of which has two sub-questions.

> Overarching Research Question (RQ):
>
> How does ecosystem service mapping contribute to landscape conservation and what are the constraints of this approach?

The overarching RQ addresses the capacity of ES mapping and valuation to contribute to the preservation of the Montado landscape. The objective is to test the extent of ES provided by the landscape, how this information can help to influence decision-making and to investigate the validity of ES maps. The following sub-questions help to analyze specific aspects of the overarching RQ.

[1] InVEST = Integrated Valuation of Ecosystem Services and Tradeoffs, www.naturalcapitalproject.org/InVEST.html.

Research Theme #1 (RT-Mapping): Mapping Ecosystem Services in the Montado Landscape

RQ1: What level of ecosystem services can the Montado landscape provide?

RQ2: How do changes in land-use and land-cover influence the ability of the Montado landscape to provide ecosystem services?

First, I investigate the ability and extent of the current Montado landscape to provide ES, specifically the provision of cork, carbon storage and sequestration, and recreational values. Secondly, I explore how changes in land-use and land-cover (LULC) influence the landscape's ability to provide these services by applying three future scenarios – *Urbanization*, *Cattle Intensification* and *Forest Improvement* – to the study area and analyzing their ES performance.

Research Theme #2 (RT-Validity): Validity of ES mapping

RQ3: How accurate and reliable are ecosystem service maps in general?

RQ4: How valid and precise are the InVEST model outputs for the Montado case study?

ES maps are a helpful tool which gained momentum over the past decade. However, there is growing skepticism towards its accuracy and usefulness for decision-making. I investigate the inherent advantages and disadvantages of ES mapping and analyze current trends within the scientific literature. With the fourth question I dissect the carbon and timber model of the InVEST toolkit and test them for their validity and accuracy.

2. Theoretical Framework

2.1. The Ecosystem Service Concept, Nature Conservation and Sustainability Science

2.1.1. A Brief History of Ecosystem Services

The ES concept seeks to identify and quantify the functioning and flows of ecosystems for human well-being. The concept is comparatively young but has expanded noticeably since its beginnings 30 years ago. In particular, the incorporation into the Millennium Ecosystem Assessment (MA) and the subsequent Sustainable Development Goals amplified its recognition and popularity (Brendan Fisher, Turner, & Morling, 2009). Several definitions emerged to describe the character of the ES concept. For this thesis I will employ the definition of the MA (2005) as it is widely used in scientific literature and features a clear structure: Ecosystem services are the benefits people obtain from ecosystems.

CICES categorizes ES in three main sections: Provisioning*,* Regulation & Maintenance*,* and Cultural (Haines-Young & Potschin, 2013; Figure 1). Each section is broken down into divisions according to their main type of output or process (Haines-Young & Potschin, 2013; Figure 1). I will apply the CICES framework for this thesis as it is also used in OPERAs (Nicholas, Walz, & Wilson, 2014) and its sister project OPENNESS (Haines-Young & Potschin, 2014).

Section	Division	Group
Provisioning	Nutrition	Biomass
		Water
	Materials	Biomass, Fibre
		Water
	Energy	Biomass-based energy sources Mechanical energy
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota
		Mediation by ecosystems
	Mediation of flows	Mass flows
		Liquid flows
		Gaseous / air flows
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
		Pest and disease control
		Soil formation and composition
		Water conditions
		Atmospheric composition and climate regulation
Cultural	Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings]	Physical and experiential interactions
		Intellectual and representational interactions
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes [environmental settings]	Spiritual and/or emblematic
		Other cultural outputs

Figure 1: Ecosystem service categorization as proposed to the European Environmental Agency. ES are categorized in three main sections and further divided into divisions and groups. This categorization was presented in the Report to the European Environment Agency. Source: (Haines-Young & Potschin, 2013).

2.1.2. Between Two Trends – Ecosystem Services in Conservation Science

The ES concept can be seen as an integral part of conservation science. The purpose of valuating ES is, eventually, the preservation of the study object, hence nature conservation. However, within conservation there are two factions which either include or exclude the idea of using ES for conservation (Mace et al., 2012). Per definition, the ES concept includes humans as recipient of nature's services (see Chapter 2.1.1). Thus, ES originate from an anthropocentric viewpoint (Goulder & Kennedy, 1997).

In recent years, the conservation community engaged itself in a "lively, if not divisive, discussion about the validity of different values and motivations behind conservation" (Cambridge Conservation Forum, 2014). On the one hand, there is the traditional faction that sees an *intrinsic value* in nature and proposes to conserve nature for its own sake (Doak, Bakker, Goldstein, & Hale, 2014; Tallis & Lubchenco, 2014). On the other hand are the so-called *new conservations science*, who represent the idea of an instrumental value to nature which should be conserved to benefit humans (Doak et al., 2014; Tallis & Lubchenco, 2014). Choosing one school of thought has certain implications for the availability of tools, the ways of measuring success and your potential partners and collaborators within the project (Mace, 2014).

By employing InVEST in this thesis I use a tool which belongs to the *new conservation science* faction. This does not mean, however, that I adopt all beliefs and arguments to the full extent. For a detailed overview of arguments for both factions see Doak et al. (2014), Mace et al. (2012), Mace (2014), Polasky et al. (2012) and Tallis and Lubchenco (2014). I rather seek to use this valuation tool as a supplement for the conservation argument, and not as its core purpose.

2.2. Research Methodology

2.2.1. Addressing the Research Themes and Research Questions

Since the two research themes cover different aspects of sustainability science I use different tools and methods for each theme and the subsequent RQs. Table 1 gives an overview of the themes, the RQs, the methods applied as well as the data sources.

Table 1: Research methodology overview. The table presents an overview of the research themes and their subordinate RQs. The third column shows the respective method while the fourth contains the data sources.

Topic	Research Question	Method	Data Sources / Data Collection
Research Theme #1: Mapping ES in the Montados	**RQ1:** What level of ecosystem services does the Montado landscape support?	Applying the InVEST models to the base scenario	GIS Maps
			Literature Databases
			Resources from the University of Lisbon
	RQ2: How do changes in land-use and land-cover influence the ability of the montado to provide ecosystem services?	Applying the InVEST models to the three future scenarios	GIS Maps
			Literature Databases
			Personal Communication with Researchers and Stakeholders
			Resources from the University of Lisbon
Research Theme #2: Validity of ES mapping	**RQ3:** How accurate and reliable are ecosystem service maps in general?	Literature Review	Literature Databases
	RQ4: How valid and precise are the InVEST model outputs for the Montado case study?	Uncertainty-Analysis of the carbon and timber model plus personal user experience	Personal User Experience
			Input Uncertainties
			Model Visualization

RT-Mapping is addressed by applying three InVEST models to the study area and three future scenarios. RQ1 focuses on the Montado's present ability to provide ES and can be answered by applying InVEST to the base scenario. RQ2 targets ES provision under different land management scenarios and is addressed by using InVEST's scenario analysis capacities.

To answer RT-Validity I conduct a literature review (RQ3) and run an uncertainty analysis regarding input variables used to run the InVEST models for this study, complemented with my own experiences using these models (RQ4). The overarching RQ is answered by gathering the results for the four sub-questions and synthesizing these in the discussion section.

2.2.2. Research Theme #1: Using InVEST to Measure ES in the Montado

To address RT-Mapping I apply three models of the InVEST toolkit to the study area Companhia das Lezírias, namely Carbon Storage and Sequestration: Climate Regulation (carbon model), Managed Timber Production (timber model), and Visitation: Recreation and Tourism (recreation model). The timber and carbon models address Provisioning and Regulating & Maintenance ES respectively, while the recreation model addresses cultural ES. Each model is applied to the current Charneca landscape (base scenario) plus three future scenarios (see Chapter 4.1.1).

InVEST is a spatially explicit toolkit developed by the Stanford-based Natural Capital Project (Nelson et al., 2009). It "is a suite of software models used to map and value the goods and services from nature that sustain and fulfill human life" (The Natural Capital Project, 2015, "Toolbox InVEST"). InVEST allows to compare different LULC scenarios to project how changes in ecosystems will affect the provision of ES and recognize ecosystem trade-offs (Sharp et al., 2014). Thereby, InVEST enables users to identify areas which are suitable for investment in ecosystem preservation while providing services for humans (Sharp et al., 2014).

2.2.3. Research Theme #2: Literature Review and Uncertainty Analysis to Assess ES Mapping

I will answer RQ3 by reviewing the current literature regarding ES maps and ES mapping tools with special attention to comparative analyses and methodological reviews. The literature is obtained via Web of Knowledge, Google Scholar, and through my colleagues from the OPERAs project and the University of Lisbon.

To answer RQ4 I will conduct an uncertainty analysis. InVEST is a comparatively new suite of ES mapping tools and the amount of published studies which used InVEST for ES mapping is manageable. To my knowledge, none of the published studies conducts a valuation of their results with regards to the internal structure of InVEST and the input data quality. I want to disclose the structure of the carbon and timber model plus the data input quality in order to demonstrate the functioning of InVEST, raise awareness for potential data distortions, and increase the transparency of this study.

Due to the lack of previous analysis of the InVEST carbon and timber models, I developed an approach to visualize and quantify my experiences. In a first step I list all input variables for the models in an excel-spreadsheet (see Appendix A and B) which contains the required file type, the data source, an explanation on how I handled the data, and comments. Further, I added the 'degree of certainty' which ranks each input according to the data's degree of certainty. The classification is deliberately simple and consists of three degrees: high, medium and low. Box 1 shows three examples of the ranking process. I did the ranking according to my own and my colleagues' estimations and opinions while trying to remain as consistent as possible. Still, this results in a relatively high degree of subjectivity for the ranking. Further, it is important to note that these rankings are linked to the specific case of this study area and data availability and accuracy will change depending on the chosen study area.

Box 1: Examples for the certainty rankings. The box gives an example for each certainty ranking to show how I used the ranking scheme on the input variables. The examples represent actual input data and shall clarify my decisions. For further details on the ranking process see Appendix A and B.

High certainty: *Frequency of harvest periods* (freq_harv).
The forest manager of Companhia das Lezírias, Rui Alvez, personally told me that they harvest their cork parcels in a 9-year rhythm. The information source is credible and the information fully represents reality.

Medium Certainty: *Market discount rate*.
I employed the InVEST userguide's recommendation of 7%. However, this number holds true for American environmental project and is said to change depending on country and landscape. Since I was not able to obtain precise number for Portuguese montados I think that 7% will not fully reflect reality, hence is ranked as medium.

Low Certainty: *Half-life of wood products* (decay_cur/fut).
70% of raw cork is processed to bottle stoppers. The half-life of a bottle stopper after is product cycle greatly depends on waste management of the usage location. If immediately incinerated there is hardly any carbon storage function. On a land-fill, however, cork decays slowly and carbon would be retained from the atmosphere. But due to the high uncertainty of what actually happens to bottle stoppers, I ranked this value as lowly certain.

Secondly, I visualize the models by providing an overview of all required inputs, helping to understand the relations between the variables and adding the respective certainty rankings (see Figure 17 and Figure 18). As a last component of the validity analysis I will discuss general problems and shortcomings of the process and my experiences with data sourcing, running the model, and communicating with stakeholders and colleagues (see Chapter 5.2.2.3).

2.3. Ontological and Epistemological Considerations

Since the thesis follows a two-tiered approach by analyzing ES in the Montado (RT-Mapping) and testing the validity of ES mapping (RT-Validity) I will address biophysical questions about ES provision using a logical positivist perspective, and the critical human application and understanding of these results using an interpretivist perspective. The thesis is located at the complex intersection between natural and human systems and could be seen as critical realist (Dryzek, 1997). However, a review of the two RTs shows that from a philosophical viewpoint these parts hardly fit into a common scheme and thus require separation. Figure 2 shows the natural and human sphere as well as the intersecting area where sustainability science is located.

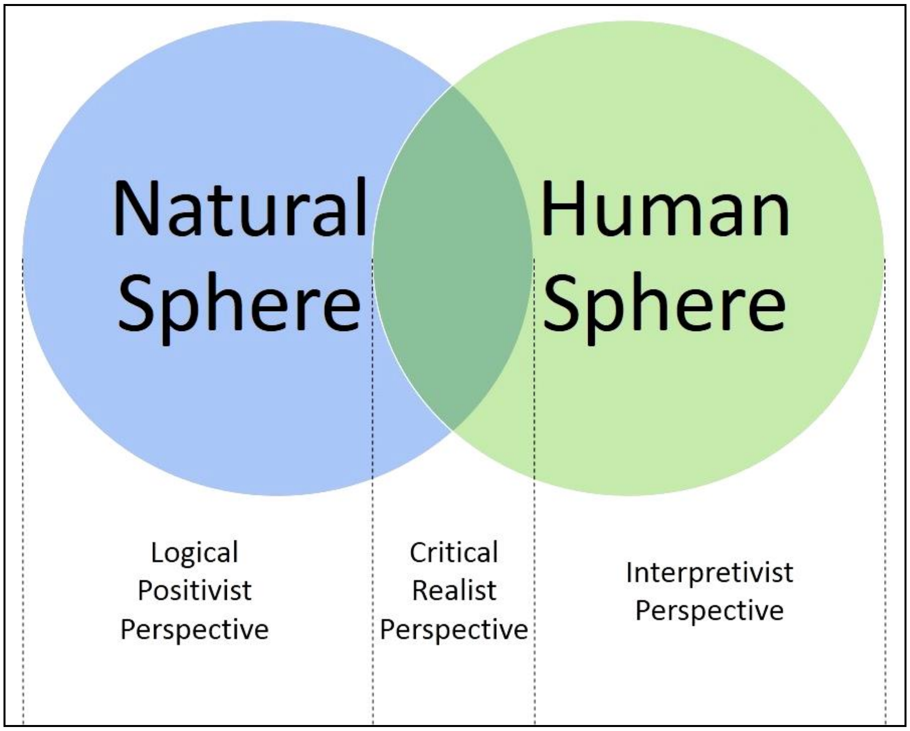

Figure 2: Philosophical structure for the thesis.The two spheres, natural and human, can be viewed separately from an epistemological viewpoint. While the natural sphere is observed with objectivist approaches such as logical positivism, the human sphere requires a subjectivist approach, such as interpretivism. Where both sphere overlap, an epistemology which includes elements of both approaches might be applicable, for example critical realism.

Modelling ES with a spatially explicit tool (RT-Mapping) is an objectivist method and is based on the belief in a reality which can be either logically deducted or empirically proved or falsified. One core concept of logical positivism is the verification principle which states that for empirical hypotheses “some possible sense-experience should be relevant to the determination of its truth or falsehood” (Ayer, 1936, p. 2). Further, logical positivism resembles modeling in the sense that models use empirical data, analyze it and produce results based on logical relations. This directly relates to the key principle of logical positivism as it represents “reasoning based on two key concepts, the collection of experiences yielding empirical data and the logical analysis of this data” (Juma'h, 2006, p. 89)

The critical analysis of ES mapping and the InVEST tool in particular (RT-Validity) is fundamentally different in its epistemological approach than the mapping process. By analyzing ES maps and InVEST I seek to understand the internal functioning of ES mapping and draw conclusions from these insights. Since the process of understanding "cannot be measured or counted […] there is always an interpretive or hermeneutic element in social science" (Sayer, 2000, p. 17). Thus, I will apply an interpretivist dimension for this part of the thesis. I acknowledge my active role as an investigator and am aware of the subjectivity that is inherent to the analysis (Strunz, 2012). Hence, my research cannot be objective and my perspective needs to be considered when viewing the results. In the discussion section I merge both perspectives in the broader picture of the sustainability science and its intersection between human and natural sphere.

3. The Mediterranean Cork Oak Savannah – A Unique Landscape

3.1. Collaboration with the OPERAs Montado Exemplar

OPERAs is a project under contract from the European Commission (Nicholas et al., 2014) which operates under the title *Ecosystem Science for Policy & Practice* and encompasses 27 partners from academic institutions, consultancies as well as small and medium enterprises (OPERAs, 2015). OPERAs seeks to bridge the gap between science, policy and practice with regards to natural capital and ecosystem services. Special focus lies on the identification and quantification of ecosystem services and their "potential for the operational use […] across a variety of settings" (Nicholas et al., 2014, p. 6).

This thesis is embedded in the Montado Cultural Landscape Exemplar and is conducted in collaboration with the University of Lisbon. The exemplar seeks to demonstrate "the benefits and viability of agro-forestry systems" (Santos-Reis, Rebelo, & Máguas, 2014, p. 41) with the goal to simultaneously improve high quality agricultural production and the ES provision. The exemplar is conducted at Companhia das Lezírias (Companhia) – a publically owned farmstead located north-east of Lisbon (Figure 3). Companhia consists of three main areas of land: Lezíria Norte, Lezíria Sul and Charneca. It is the "largest agriculture, cattle and forest farmstead in Portugal" (Companhia das Lezírias, 2015, "Quality and Tradition").

This study will focus on Charneca which has a total area of 11,000 ha with 6,500 ha covered with cork oak Montado (Figure 3) making it one of the largest, single-handedly owned properties with cork oak stands in Portugal (M. Santos-Reis, personal communication, February 11, 2015). Other prominent land-uses are monocultures of Eucalyptus species (601 ha) and Maritime Pine (Pinus pinaster, 872 ha) for timber production, Stone Pine (Pinus pinea, 227 ha) for pine nut production, and annual crop land (1087 ha).

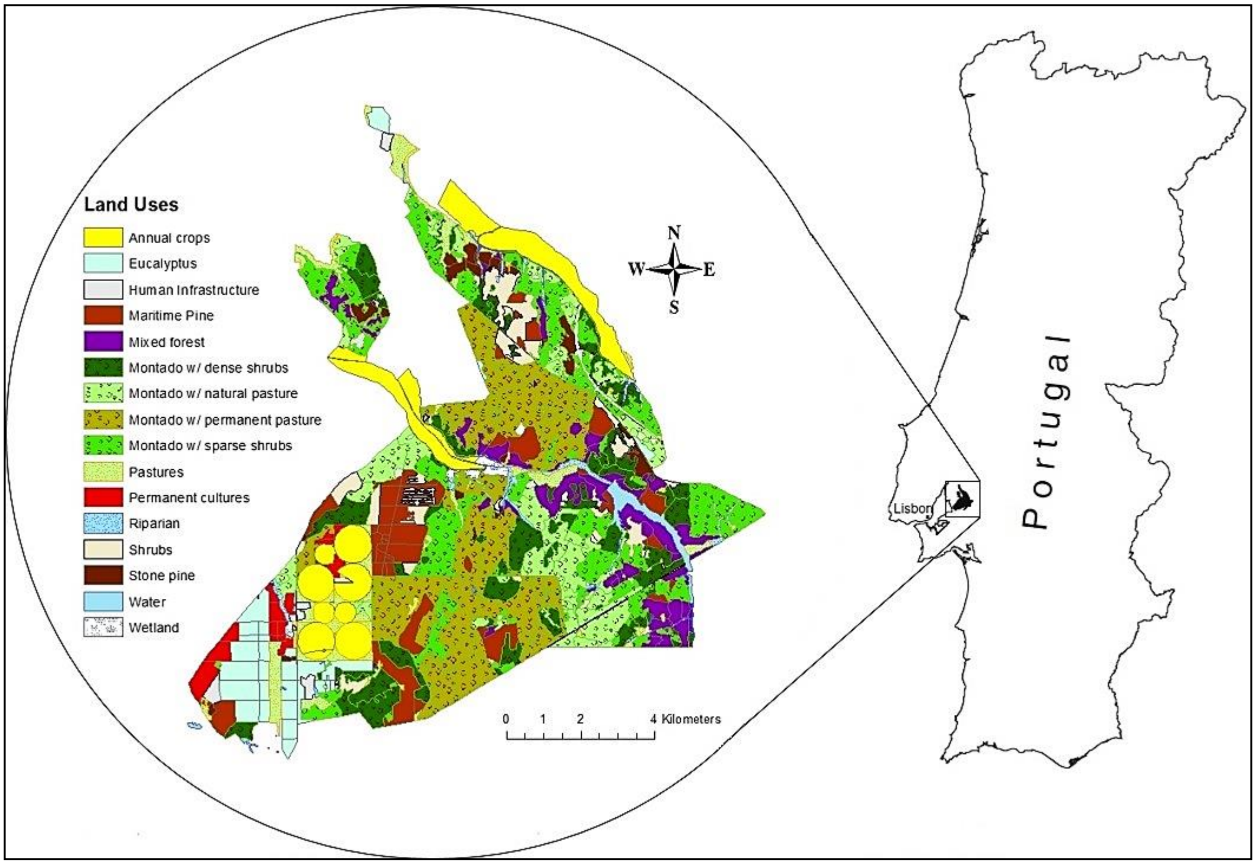

Figure 3: Map of the Companhia das Lezírias and the current land-use and land-cover patterns. The area covers around 11,000 hectare and is located 50 km north-east of Lisbon. There are 16 LULC classes, four addressing different types of Montado. Source: own illustration based on Gonçalves et al. (2011).

Companhia follows a sustainable development philosophy since 1997 and manages its land according to traditional farming methods, including a Forest Stewardship Certification, natural regeneration of cork trees, and a focus on increasing the cork savannah landscape (Companhia das Lezírias, 2015). The majority of Montado is used for cattle grazing which rotate in herds of 50 – 300 animals (Gonçalves et al., 2011).

3.2. The Montado Ecosystem

3.2.1. Cork Oak Woodlands and Humans – A Fruitful Combination

The cork oak (*Quercus suber)* is an evergreen species in the genus *Quercus* (lat. oak tree) which is home to the Western Mediterranean basin (Pereira & Tomé, 2004). Cork oaks appear sympatrically with holm oaks (*Quercus ilex*) in many regions and form the savannah-like landscape known as Montado in Portugal and Dehesa in Spain. Figure 4 shows the distribution of cork oaks (green) and holm oaks (blue) in Portugal. Cork oaks prefer a more humid climate resulting in a western and coastal distribution (Pinto-Correia, 2000). Covering up to 2 million hectare of land, Montados are a significant landscape in wide areas of the

Mediterranean – Portugal alone supporting 800,000 hectare of cork oak savannahs (Pereira & Tomé, 2004; Pinto-Correia et al., 2011).

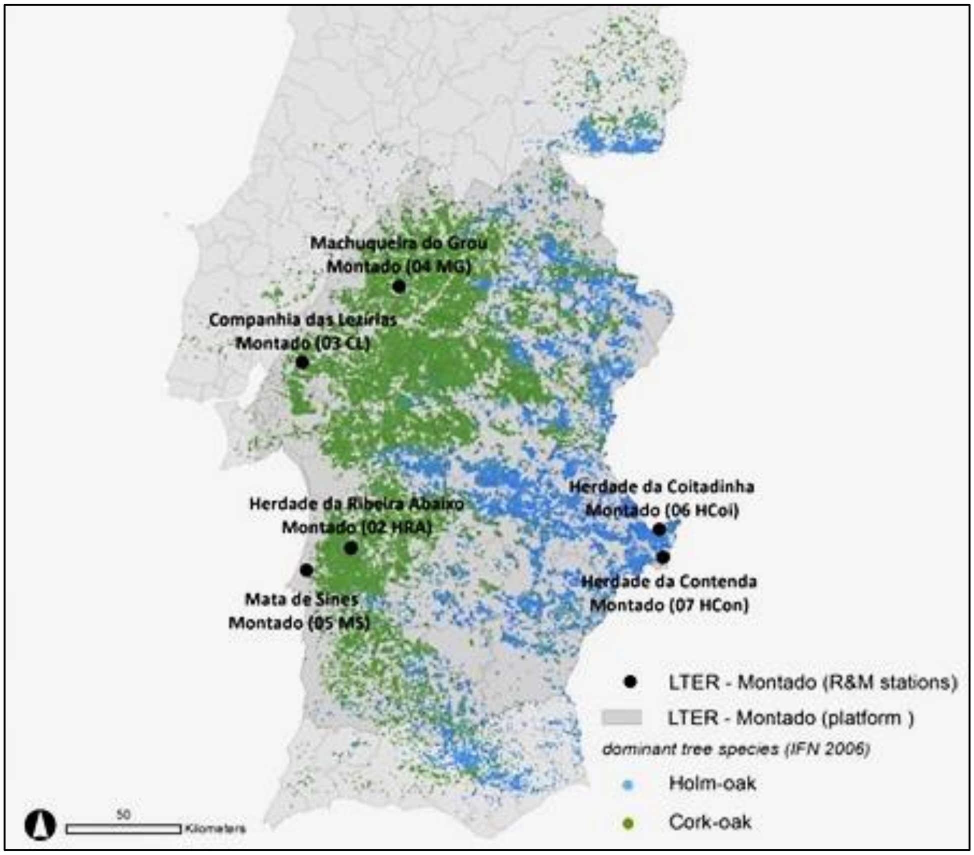

Figure 4: Distribution of cork oaks (Q. suber) and holm oaks (Q. ilex) in Portugal. The green areas show the distribution of *Q. suber* in Portugal with the densest populations in the south-western parts of the country. The blue areas show the distribution of *Q. ilex* which is more frequent in the south-eastern part. Both species occur sympatrically, mostly in the central southern region of Alentejo. The black dots represent research station of the LTER Montado program. Source: Santos-Reis et al. (2014).

The Montado is a human-shaped system which can be defined as an "agro-silvopastoral system" (Surová, Surový, de Almeida Ribeiro, & Pinto-Correia, 2011, p. 1) and supports various production activities including grazing, livestock, pasture, agriculture, and non-timber products (Pinto-Correia et al., 2011). The heterogeneous character of the Montado creates the unique mosaic (Figure 5) which provides suitable habitat for a large number of species, e.g. the critically endangered Iberian lynx (*Lynx pardinus*) (Bugalho, Caldeira, Pereira, Aronson, & Pausas, 2011; Pinto-Correia et al., 2011).

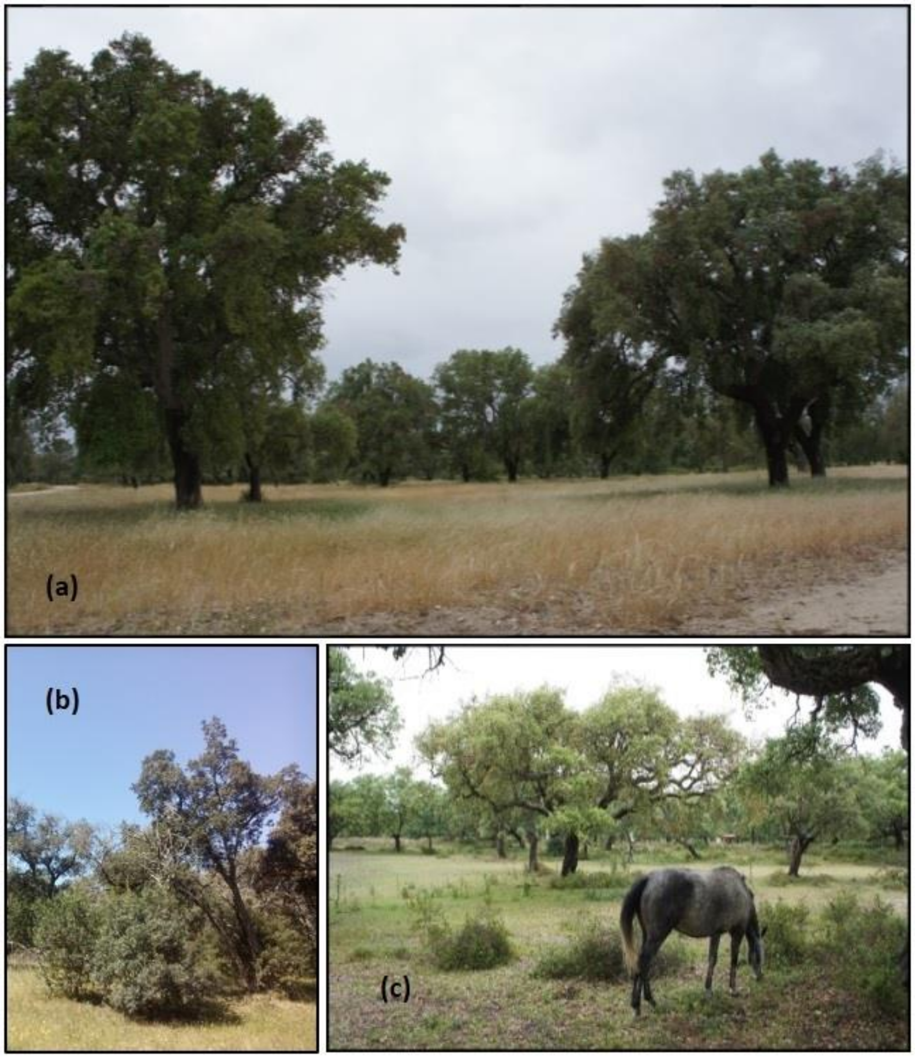

Figure 5: Examples of Montado landscape. (a) and (c) are examples of Montado in the study area Companhia das Lezírias and represent pure cork oak Montado. Picture (b) shows a mixed forest including cork oaks and shrubs, taken in Monsanto Park, Lisbon. Photographs: Marius von Essen.

This distinctive composition of the Montado is a result of moderate human interaction and biophysical traits of the landscape, such as soil composition, landscape morphology, and water availability (Almeida & Pinto-Correia, 2012). Human intervention includes shrub clearing by grazing or manual clearing as well as agricultural activities like livestock farming, and fodder and cereal production (Bugalho et al., 2011; Pinto-Correia et al., 2011). Further, Montados are used for bee keeping, mushroom picking, game hunting, and a set of recreational activities (Pereira & Tomé, 2004). During the past decades the public appreciation increased and today the Montado landscape is esteemed for its aesthetic value, identity preservation and its recreation activities (Pinto-Correia et al., 2011).

3.2.2. Cork – Montado's Most Valuable Asset

One feature that separates cork oaks from other species is its thick bark composed of layers of cork tissue which may have evolved as a result of the periodic fires (Aronson, Pereira, & Pausas, 2009; Bugalho et al., 2011). The bark has the capacity to regrow once the old layer has been removed (Pereira & Tomé, 2004). The raw material is harvested by extracting the bark without felling the trees which enables the tree to regenerate after each harvest (Aronson et al., 2009). Cork is comparatively light and rather impermeable for liquids thus used in various fields and forms, for example as sealants, for insulation, as buoys, floor surfaces, and anti-vibrational joints (Pereira & Tomé, 2004).

In 2013, Portugal produced 100,000 tons raw cork and accounted for 63.9 % of the worldwide cork exports[2] (APCOR, 2014). This makes cork significant for the economic sustainability of cork oak woodlands as it provides employment and income for many seasonal workers and land-owners. In 2012 the cork industry employed approximately 9,000 workers in almost 650 factories (APCOR, 2014). Cork production and processing are the biggest industries in the Montado and their success is closely linked to the landscape's intactness.

Cork production is a long-term business as the first harvest usually happens when the trees are around 30 – 40 years of age (Bugalho et al., 2011), and as a slow-growing species harvest takes place only every 9 – 12 years (Bugalho et al., 2011). This makes the cork producing industry comparatively slow to react to market demands and changes in customer preferences.

3.3. Future Challenges for the Montado

The traditional farming practices which formed the Montados are increasingly subject to pressures, both internal and external. These pressures have different natures and affect land management practices (Figure 6). The two most widely recognized superordinate threats to the balance of the Montado system are land-use intensification and extensification (Almeida, Guerra, & Pinto-Correia, 2013; Pinto-Correia, 2000). Both problems are driven by several causes and result in the deterioration of the Montado (Figure 6). The high environmental and social importance and the uncertain future of the Montado make this landscape suitable for ES mapping under different future scenarios contrasting agricultural intensification with alternatives.

One cause for agricultural intensification is the replacement of traditional livestock (goat and pig) by cattle – partly due to the EU Common Agricultural Policy which provided higher financial support per capita of

[2] Monetary value: 834.9 million €.

cattle than for smaller ruminants (Bugalho, Plieninger, Aronson, Ellatifi, & Gomes Crespo, 2009). Generally, cattle production promises faster and higher returns on investment compared to cork production. Recent studies suggest that overgrazing could be detrimental for natural tree regeneration and consequently lead to a lack of juvenile trees in the system (Almeida et al., 2013; Bugalho et al., 2011; Plieninger & Pulido, 2009; Personal Communication M. Bugalho, February 11, 2015).

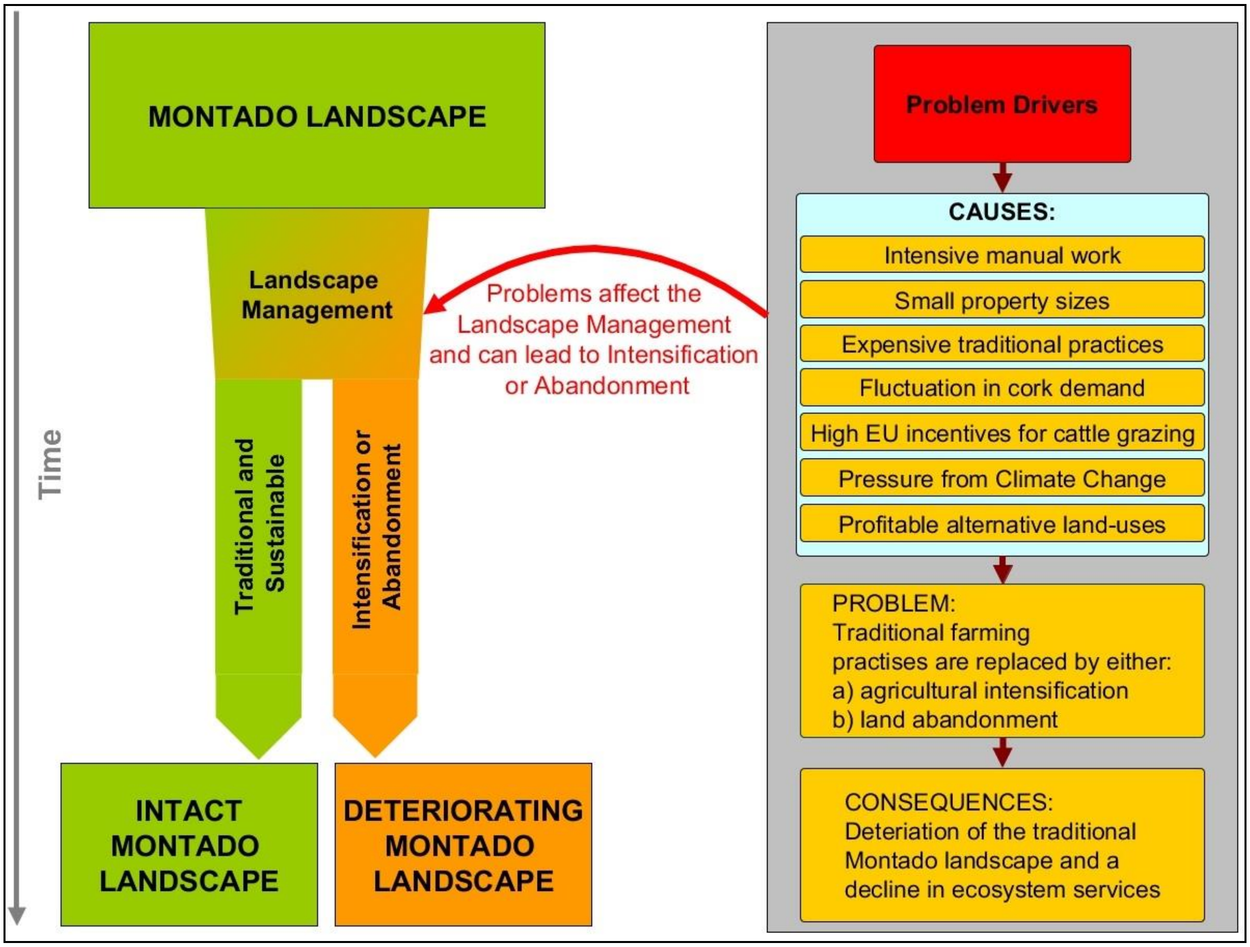

Figure 6: Pressures for the traditional Montado management. An intact Montado landscape is reliant on traditional and sustainable farming practices. However, growing pressures on the decision-makers increase the change towards more intense farming techniques or land abandonment. This leads to a deterioration of the Montado and its values.

Traditional management techniques are labor intensive and expensive. Manual shrub clearing, for example, is physical work and is increasingly replaced by automated methods such as soil disking, mechanized plowing and chemical control (Almeida et al., 2013). These methods pose higher risk to the balance of the system by reducing the water carrying capacity and organic content of the soil (Almeida et al., 2013; Pinto-Correia et al., 2011). Further, agricultural wages increased over the past decade and the active rural population has been decreasing since the 1960’s (Bugalho et al., 2011). This leads to growing economic pressure, especially for small-scale land owners (M. Bugalho, personal communication, February 11, 2015) and eventually to non-sustainable land management decisions.

Conventional large-scale farming (e.g. corn, pine nuts, and cattle production) requires less work and promises higher and more constant income. Former cork oak stands are increasingly substituted by umbrella pines (*Pinus pinea*) which provide highly valuable pine nuts and timber (M. Bugalho, personal communication, February 11, 2015). These species are not native to the Iberian Peninsula and do not require the same land management techniques that shaped the unique Montado landscape.

Another pressure for the Montado is the variation in cork demand. Between 2000 and 2010 the cork price has been subject to fluctuations and displays an overall negative trend.[3] These variations are closely linked to the demand from the wine and champagne industry since 70 % of the cork is used for bottle stoppers (Ahlheim & Frör, 2011). However, the market for bottle stoppers has become very competitive as alternative materials such as plastic, glass and aluminum are cheaper and show improvements in quality and acceptance among consumers (Ahlheim & Frör, 2011).

Extensification and land abandonment lead to shrub encroachment which has a detrimental effect on the landscape's diversity and promotes the frequency and intensity of wild fires (Bugalho et al., 2009). Additionally, areas with shrubby understory vegetation depict lower soil moisture levels indicating competition for water between shrubs and cork oaks (Cubera & Montero, 2004).

Some of the effects may be exacerbated by the influence of climate change. Climate models predict prolonged drought periods and extreme rainfall events for the Iberian Peninsula (Acácio, Holmgren, Rego, Moreira, & Mohren, 2008). This could result in more frequent wildfires, increased competition for water and an intensification of soil erosion – eventually leading to a reduction in cork oak cover and expansion of shrubland (Acácio et al., 2008).

4. Research Theme #1: Mapping ES in the Montado Landscape

4.1. Setting

4.1.1. Imagine the Future: Three Land-use Scenarios

Land management decisions made today will affect the future LULC composition of a landscape. In order to compare the consequences of these decisions it is common practice to design LULC scenarios for the study area (Kovacs et al., 2013; Nelson et al., 2009; Polasky, Nelson, Pennington, & Johnson, 2011). Scenarios depict possible future development trajectories and allow users to simulate the provision of ES

[3] For a more detailed description of cork price development see Appendix C.

under varying conditions. As mentioned in Chapter 2.2.2 InVEST is a spatial toolkit which provides the opportunity to model ES under different scenarios. For this study I developed three LULC scenarios. The scenarios have been designed in cooperation with the University of Lisbon and the forest manager of Companhia das Lezírias, Rui Alvez, and express potential management strategies of Companhia. The time horizon for the scenarios is 2050. The University of Lisbon and Companhia are in constant dialogue and started to think about future trajectories for the farmstead. I used these three initial ideas (Improving the cork oak stands, increasing the number of cattle, and allowing residential housing) and further developed them by using the knowledge, data, and opinions from University and Companhia staff members. The main variables which influence the landscape composition of Charneca are the total number of cattle and the area of Montado land-cover in Charneca. I adjusted the number of cattle with respect to each scenario: stable for *Urbanization,* increase for *Cattle Intensification,* and decrease for *Forest Improvement*. The modifications in cattle numbers are accompanied by shifts in the LULC composition (see Figure 7, Figure 8, and Appendix C). These changes were transferred into maps by using GIS software.

One main parameter for scenario development in Charneca is the total number of cattle. Cattle density influences the demand for annual crop land (which is used for fodder production) for pastures (both solely for grazing and beneath cork oaks) and shrubland (livestock reduces shrub density). Considering the financial value of cattle production plus the implications for the LULC of the area, we designed a *Cattle Intensification* scenario for Companhia which depicts an increase of cattle by 50 % from 3,000 to 4,500 animals. Accordingly, the area of annual crops for fodder production (543.5 ha), pastures for grazing (18 ha) and Montados with pasture for grazing (1,040 ha) grows by 50 %. This expansion comes at the cost of Montado area with dense shrubs, sparse shrubs and pure shrubland with a total decline of 1601.5 hectare (see Figure 8). As shown in Figure 7, the land-use changes appear among the whole study area with an emphasis on the Northern and Western parts.

The second scenario is *Forest Improvement.* In this scenario the number of cattle is reduced from 3,000 to 1,800 following the Natura 2000 suggestion of 0.5 animals ha^{-1} (Guil & Moreno-Opo, 2007) applied to the existing 3,600 hectare of pasture in the Charneca. Annual crops and pastures decrease, and the total area of Montado with shrub encroachment increase accordingly (See Figure 8). The Montado area with dense and sparse shrub encroachment grows by 1,711 hectares. As shown in Figure 7, large areas of annual crops and pastures within Montado are replaced by these two Montado types.

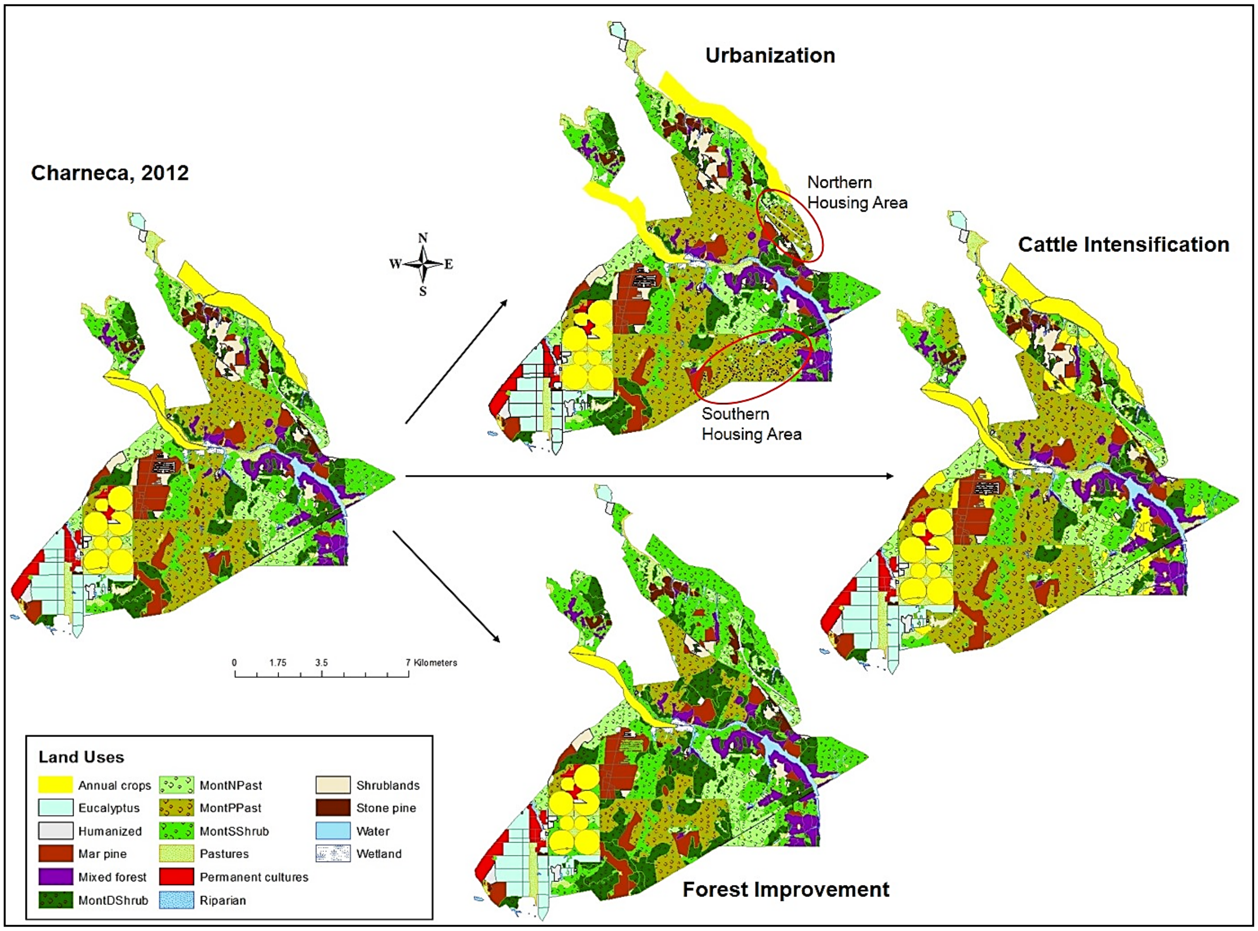

Figure 7: Charneca maps showing base and future scenarios for 2050. The figure shows the Charneca study area with 16 LULC classes and the respective changes for each scenario. *Cattle Intensification* shows an increase in annual crop land (e.g. in the Northern and Western part) and larger area of Montado with permanent pasture (e.g. south of the circular annual crop lands). *Forest Improvement* supports more Montado area in total and less Montado with pasture, noticeable in the Northern parts. *Urbanization* includes residential housing in the two highlighted areas which contained Montado before and are now intersected by houses (*humanized*).

The third scenario is called *Urbanization*. Montados have high aesthetic value and are appreciated as a destination for residential housing by the Portuguese. Privatization is not yet considered for Companhia, but is a realistic future option, especially for the highly-prized housing segment (M. Santos-Reis, personal communication, February 11, 2015; R. Alvez, personal communication, March 02, 2015). For *Urbanization*, two areas were designated for residential housing (see Figure 7). The areas are located in the south-east and north-east of the property and are close to the existing roads, to the river and contain Montado with dense or sparse shrubs, and natural pastures. *Urbanization* contains 168 houses with a *humanized* area of 525 m^2 each.

The numbers are derived by remote sensing a comparable Montado area[4] on Google Earth and calculating the average density of houses and the average area of impermeable ground each property holds. For the Northern parcel (149 ha, see Figure 7) I chose a reduced density of 0.2 houses ha^{-1} because it is intersected by a highway reducing the useable housing area. The previous land-cover is replaced with Montado with permanent pastures as this is the prevalent land-use in the reference area. I reduced the tree density from 80 trees ha^{-1} to 20 trees ha^{-1} according to a remote sensing of the previously mentioned area.

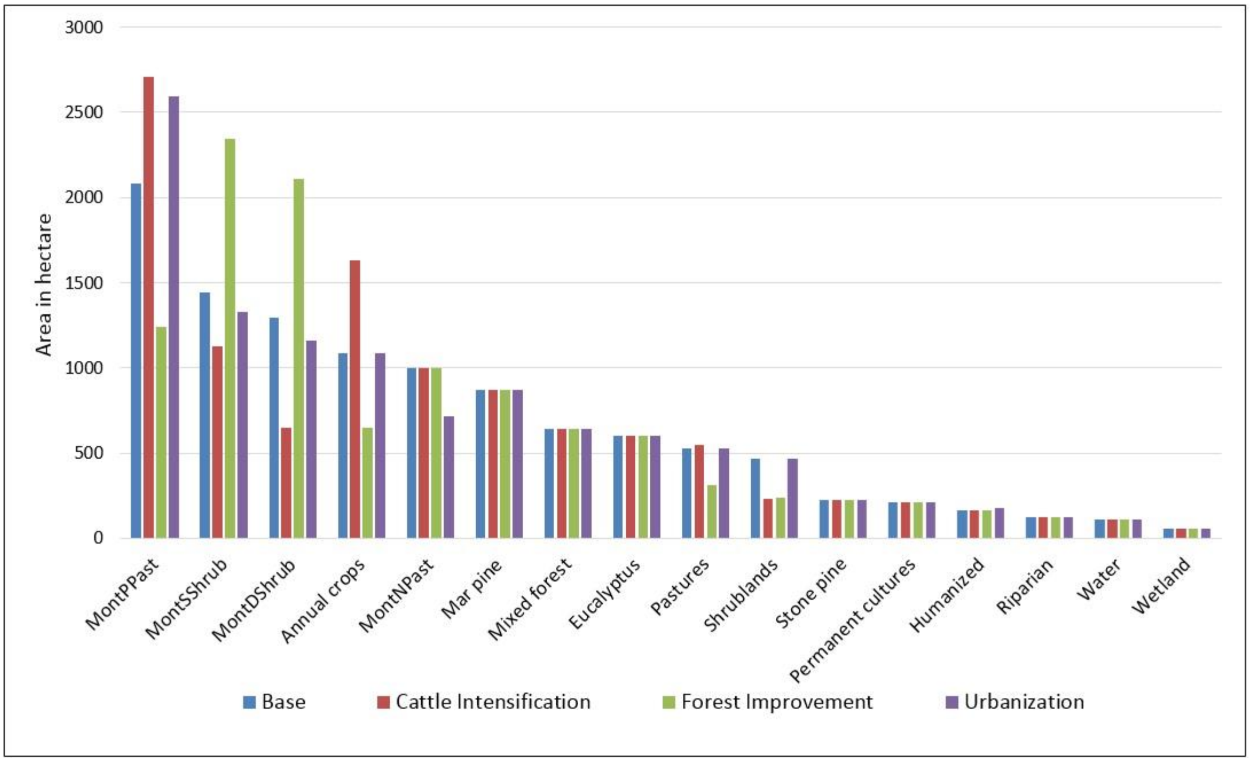

Figure 8: Distribution of land area under base and future scenarios. This bar chart shows the total area of every LULC class for each of the three scenarios in hectare. While some LULC classes are not affected by the scenarios, such as permanent cultures, Stone and Maritime Pine or water and wetlands, other LULC classes show significant changes. Especially, the four Montado types vary considerably in the scenarios. Annual cropland, pasture and shrubland show significant differences as well.

4.1.2. Introducing the Models

I modeled Cultural services using the recreation model, Regulation & Maintenance services using the carbon model, and Provisioning services using the timber model in InVEST.[5] The recreation model uses geotagged[6] photos from Flickr (an image and video hosting website[7]) to quantify visitation and a linear

[4] Area close to Santo Estevão, Latitude: 38°51'42.45"N, Longitude: 8°43'6.82"W
[5] For a more detailed description of the models see Appendix A, B, and C.
[6] Pictures with geographical identification metadata.
[7] See https://www.flickr.com/

regression to relate the photos to different LULC types. The main output is a gridded map of the study area depicting the photo-user-days per year and their relation to the LULC type.

The carbon model addresses the landscape's ability to store and sequester carbon and calculates its monetary value. It uses four carbon pools – aboveground biomass, belowground biomass, soil, and dead organic matter – to calculate the carbon content for each LULC type and allows the user to apply it to future land-use scenarios. Further, the carbon model allows a fifth carbon pool: Harvested Wood Products (for this case the harvested wood products are exclusively cork, hereinafter Cork Products). The final output of the model are raster maps which show the net amount of carbon stored in each parcel, the biomass removed from each harvest parcel, and the social and market value of carbon sequestration.

The timber model uses a dataset containing relevant harvest information such as harvest frequency, harvested biomass, and market value of harvested products. It calculates the volume and economic value of the harvested wood products. The output is vector map which contains information about the harvested mass, volume and economic value of each parcel.

4.2. Results RQ1 and RQ2: ES Mapping in the Montado Using Future Scenarios

4.2.1. Recreation Model

To assess the level of ES provided by the Montado landscape (RQ1) I used the recreation, carbon and timber model of InVEST. I further employed the models to three future scenarios to analyze the influence of changes in LULC on ES provision.

Running the initialization tool on Charneca showed that the photo-density for the area is very low (see Appendix F). The majority of grid cells do not exhibit any geotagged photographs for the years 2005 – 2012. Further, the cell with the highest photo-user-days value (0.375) happens to cover a bird-watching center. With a low number of total photo-user-days and the highest value likely to be influenced by the bird-watching center, I consider the output not significant enough to estimate the recreational value of the area. In order to avoid data bias due to the relatively small size of Charneca (11,000 ha), I ran the model with a larger study area (19,000 km²) which produced similar results. This confirms the initial impression that the number of geotagged photographs is not sufficient to derive significant results from the model. Therefore, I did not further employ the recreation model.

4.2.2. Carbon Model

The carbon model results show that carbon storage and sequestration are highest under *Forest Improvement,* lowest under *Cattle Intensification* and relatively stable for *Urbanization.* Mixed forest and

Montado with dense shrubs have the highest carbon storage value followed by the three remaining types of Montado while annual crops, human infrastructure and water show the lowest scores (Figure 9).

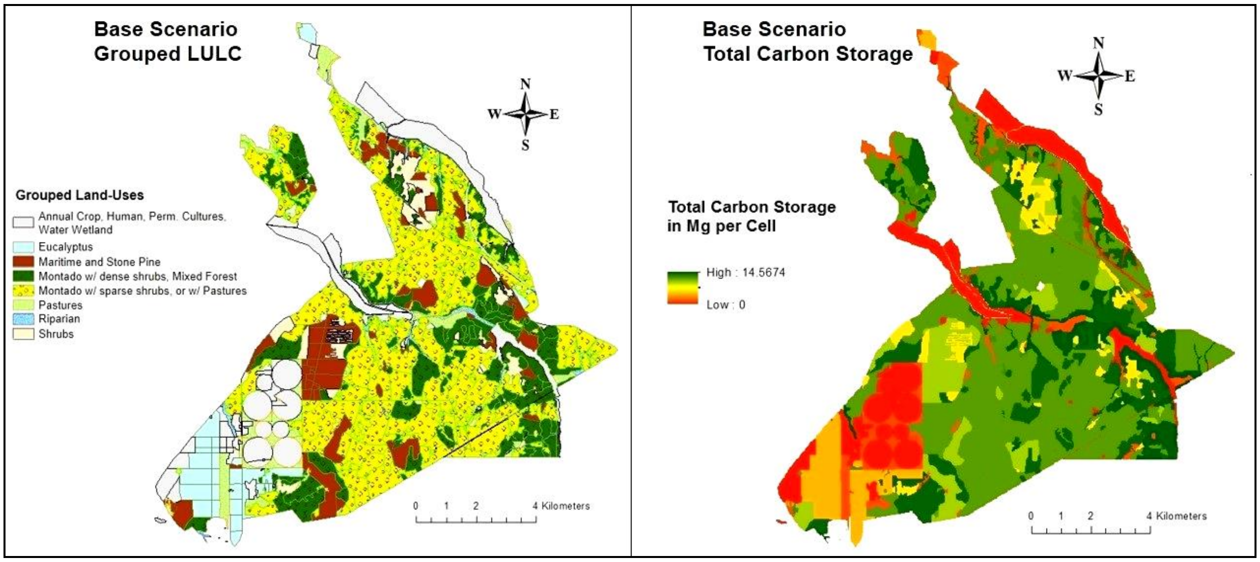

Figure 9: Charneca map with LULC classes and total carbon stock in Mg per cell. On the left is the Charneca with grouped LULC classes. The right map is a heat map showing the total stocks of stored carbon from the four carbon pools for Charneca per 30 m x 30 m cell. The color range is stretched with green representing high values (max. 14.57 Mg) of stored carbon and red low values (min. 0 Mg). The null values occur due to the lack of input for the LULC classes: *Annual Crop, Permanent Cultures, human infrastructure*, *water*, and *wetland.* These values do not represent real values since soil, water, and vegetation can still contain carbon, but are not further considered since they are not specifically addressed in this thesis.

Adding up carbon in four pools for all LULC types, the total amount in the base scenario for Charneca is 1.14 million of Mg; and 1.16 million of Mg when accounting for Cork Products (Figure 10). Further, Figure 10 shows the changes in total carbon stocks for each of the scenarios. Without considering Cork Products, only *Forest Improvement* stores a higher amount of carbon than the base scenario, namely additional 69,384 Mg (+ 6.09 %). *Urbanization* and *Cattle Intensification* show lower values than the base scenario, 2,196 Mg (- 0.19 %) and 44,080 Mg (- 3.87 %) respectively.

When considering Cork Products, the future scenarios have an increased storage potential since the model output shows "total amount of carbon that will be stored in each parcel under your future landscape scenario. It is a sum of all the carbon pools for which you have included data" (Sharp et al., 2014, p. 84). When including Cork Products *Urbanization*'s total carbon storage would be higher than in the base scenario. But, when accounting for the Cork Products under the current LULC composition, the storage is slightly higher for the base scenario than for *Urbanization.* For *Cattle Intensification*, total carbon would also increase, but still remaining below Charneca's base potential. Again, *Forest Improvement* provides the highest storage and has the largest increase when comparing *with Cork Products* and *without Cork Products*, namely 2.92 % (*Urbanization*: 2.33 %, *Cattle Intensification*: 2.15 %).

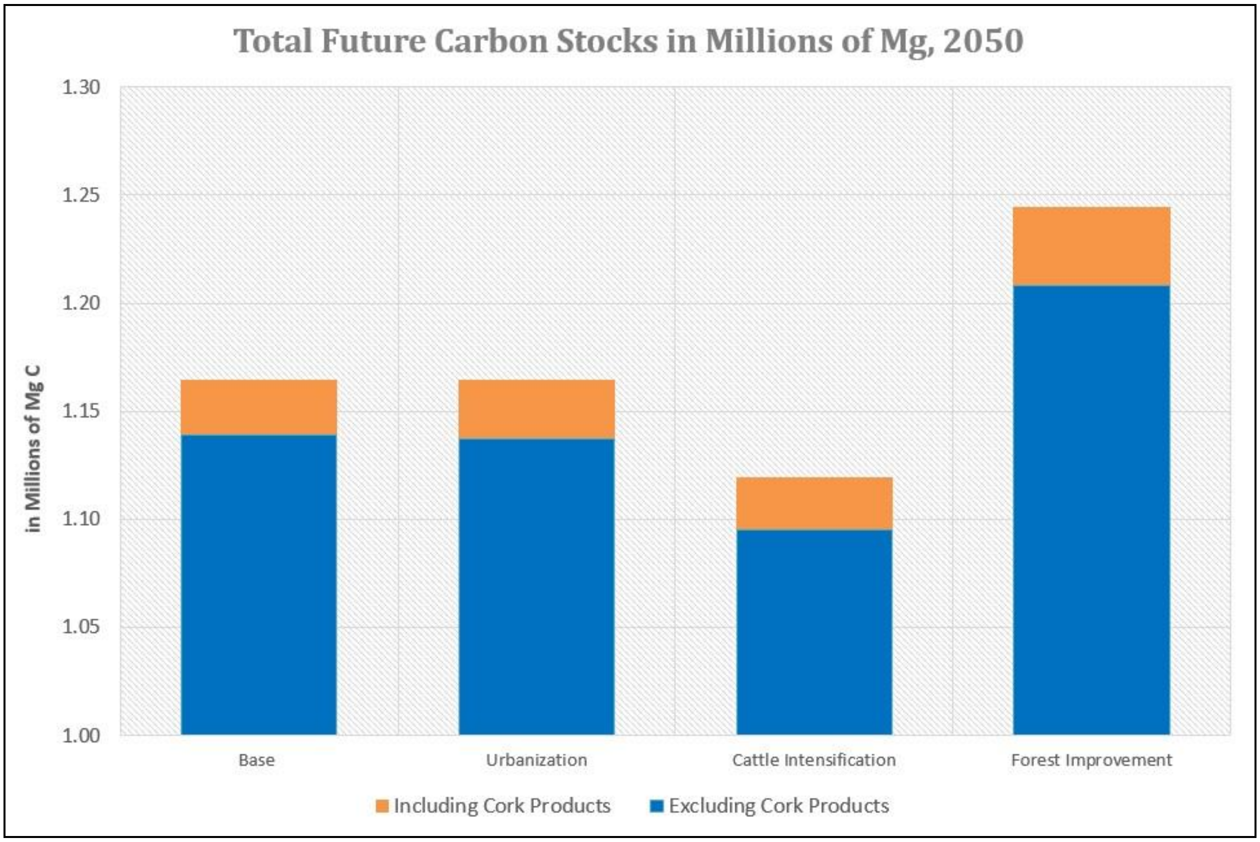

Figure 10: Total future carbon stocks in Mg for 2050 under base and future scenarios. Orange bars show the total carbon stock accounting for Cork Products while the blue bars show total carbon stocks without accounting for Cork Products (the sum of the four carbon pools: aboveground biomass, belowground biomass, soil, and dead organic matter). *Forest Improvement* shows the highest values for carbon storage, while *Cattle Intensification* performs below base. *Urbanization* depicts similar values to base. All scenarios store more total carbon when Cork Products are included.

Further, I used InVEST to visualize areas which exhibit changes in carbon storage by mapping carbon sequestration for the future scenarios. Carbon sequestration values can be negative or positive depending on whether storage increases or decreases over time. Figure 11 displays the sequestration values for the three scenarios. *Forest Improvement* shows an overall positive carbon sequestration which can be traced back to the larger total area of Montado plus the increase in harvested cork per hectare. *Cattle Intensification* shows a mottled pattern of positive and negative sequestration due to the LULC changes from Montado to either pasture or annual crop land. *Urbanization* shows few areas with negative sequestration values while most areas are either neutral or positive. The negative areas are the newly-built houses in the two designated areas. Parts of this area were transferred from Montado with dense shrubs to a Montado with sparse shrubs and a reduced harvest activity which lead to an overall decrease of stored carbon.

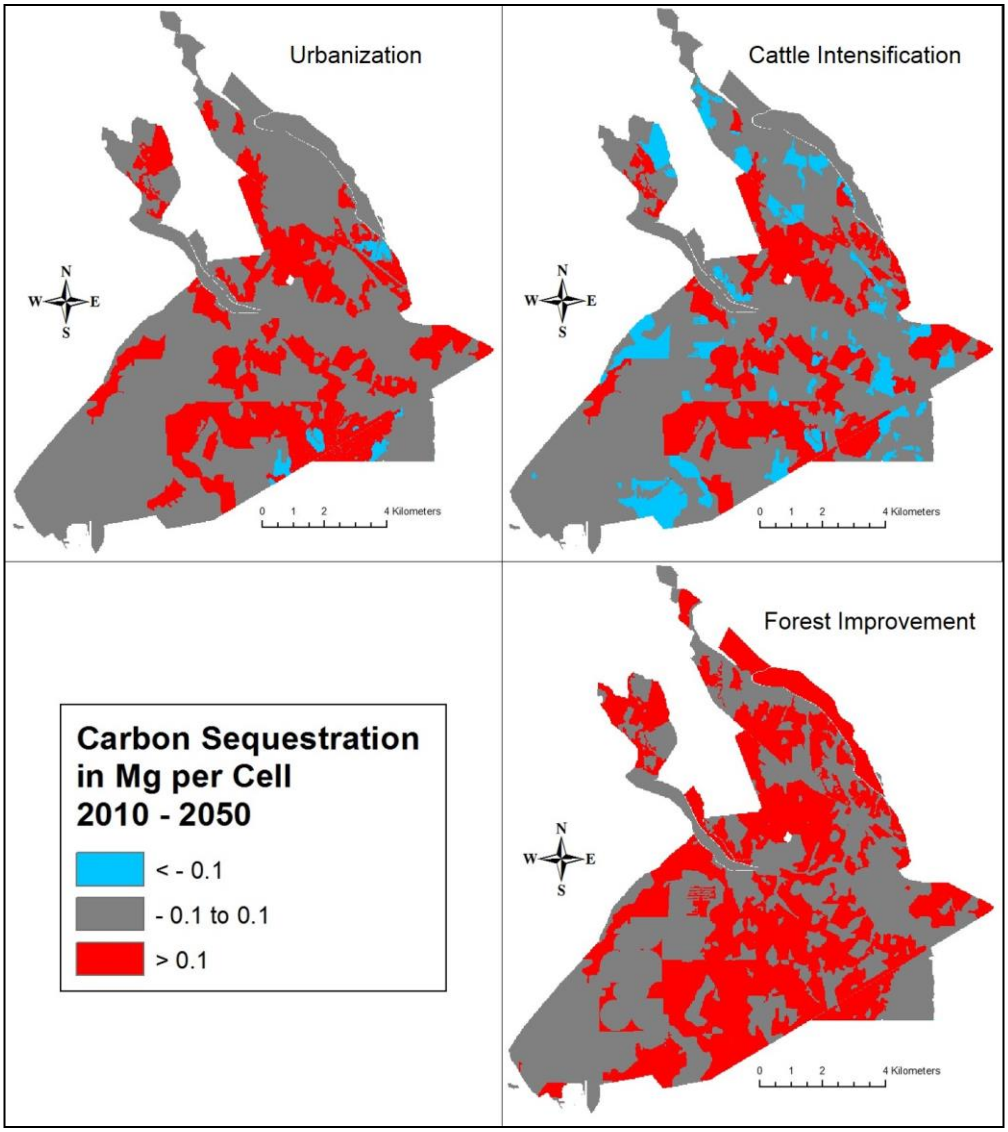

Figure 11: Carbon sequestration 2010 – 2050 under future scenarios. Carbon sequestration represents the amount of carbon that is added or removed to a landscape over a course of time. Blue areas symbolize a negative value for carbon sequestration while red areas symbolized positive values. Grey areas show no significant changes in carbon storage. *Cattle Intensification* shows a mottled image of carbon sequestration with a nearly equal number of blue and red areas. *Forest Improvement* provides overall positive sequestration values. *Urbanization* shows losses for the areas where residential houses are built, due to the subsequent change of tree density and harvested cork in these parcels.

The monetary valuation shows that a transition to *Forest Improvement* could generate over USD 2 million, while *Cattle Intensification* would result in a nearly USD 1 million loss in carbon sequestration (Figure 12).

The results are calculated based on a value for carbon per ton and discounted with a market rate of 7 %[8]. The value for carbon is USD 66.00 ton^{-1} and represents the social cost of carbon as suggested by NatCap (Sharp et al., 2014). The value is derived from a study conducted by Tol (2009) and is comparatively conservative as estimations range from USD 32 to USD 326 ton^{-1} of carbon.

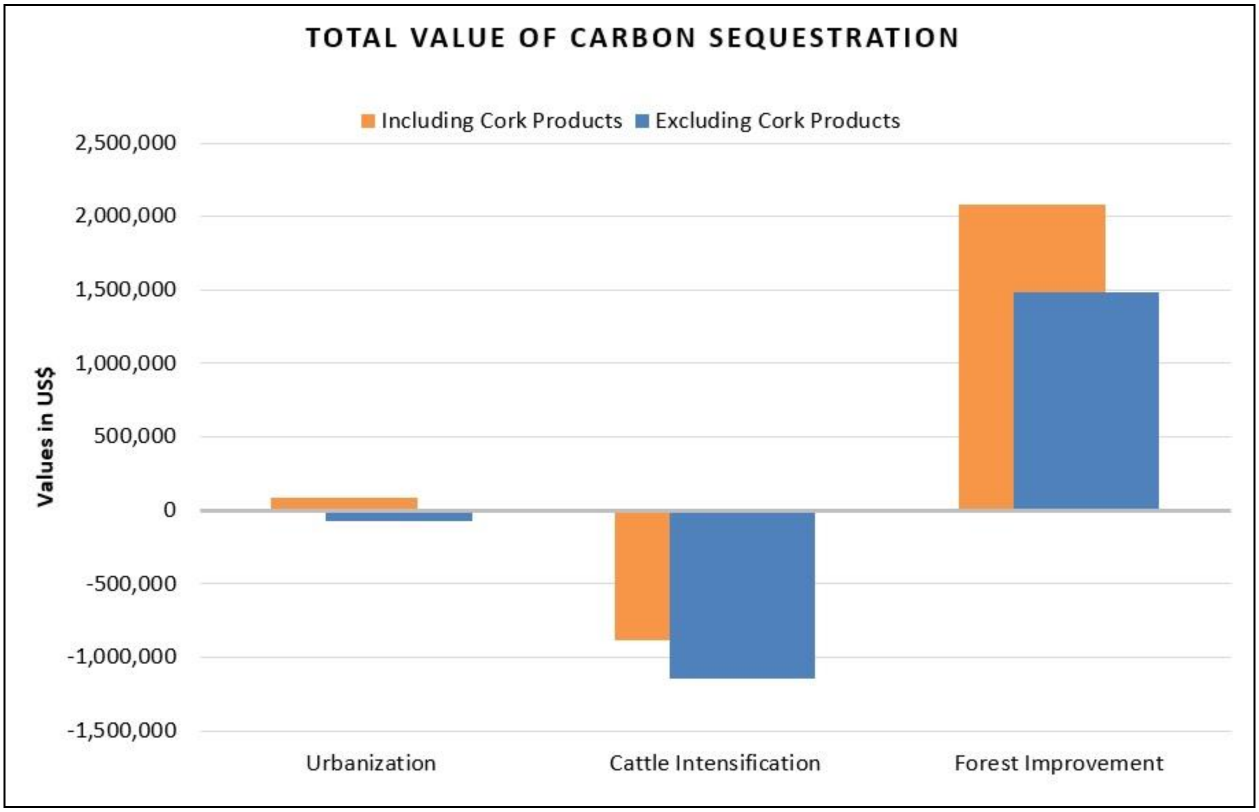

Figure 12: Total value of carbon sequestration in USD under future scenarios. Sequestered carbon can be monetized which is shown in this figure. The social cost of carbon used for the calculation was USD 66.00 with a market discount rate of 7 % per year (Sharp et al., 2014). Blue bars show the total value of sequestered carbon for each of the three scenarios without factoring in Cork Products*.* The orange bars show the same value including Cork Products. *Urbanization* shows small magnitudes indicating low values of carbon sequestration. Sequestration values for *Cattle Intensification* are entirely negative with higher magnitude than *Urbanization,* but lower values than *Forest Improvement*. *Forest Improvement* shows the highest value of sequestered carbon of the three scenarios.

The numbers show the same trend as seen in Figure 10, namely that including Cork Products leads to a higher valuation of sequestration, or, respectively, a lower loss in sequestration value (Figure 12, *Cattle Intensification*). *Forest Improvement* has the highest monetary value for carbon sequestration with an estimated price of more than USD 2 million with Cork Products and almost USD 1.5 million without Cork Products. The contrary holds true for *Cattle Intensification.* Here the sequestration value is negative with

[8] NatCap follows The US Office of Management and Budget recommendation of 7 % per annum market discount rate for US-based projects.

USD – 0.89 million and USD – 1.15 million respectively. The prices for *Urbanization* are much smaller and range below USD 0.1 million.

4.2.3. Timber – Model

In order to model provisioning ES, I applied the timber model to the base scenario and the three future scenarios. Figure 13 shows the harvested biomass per parcel.

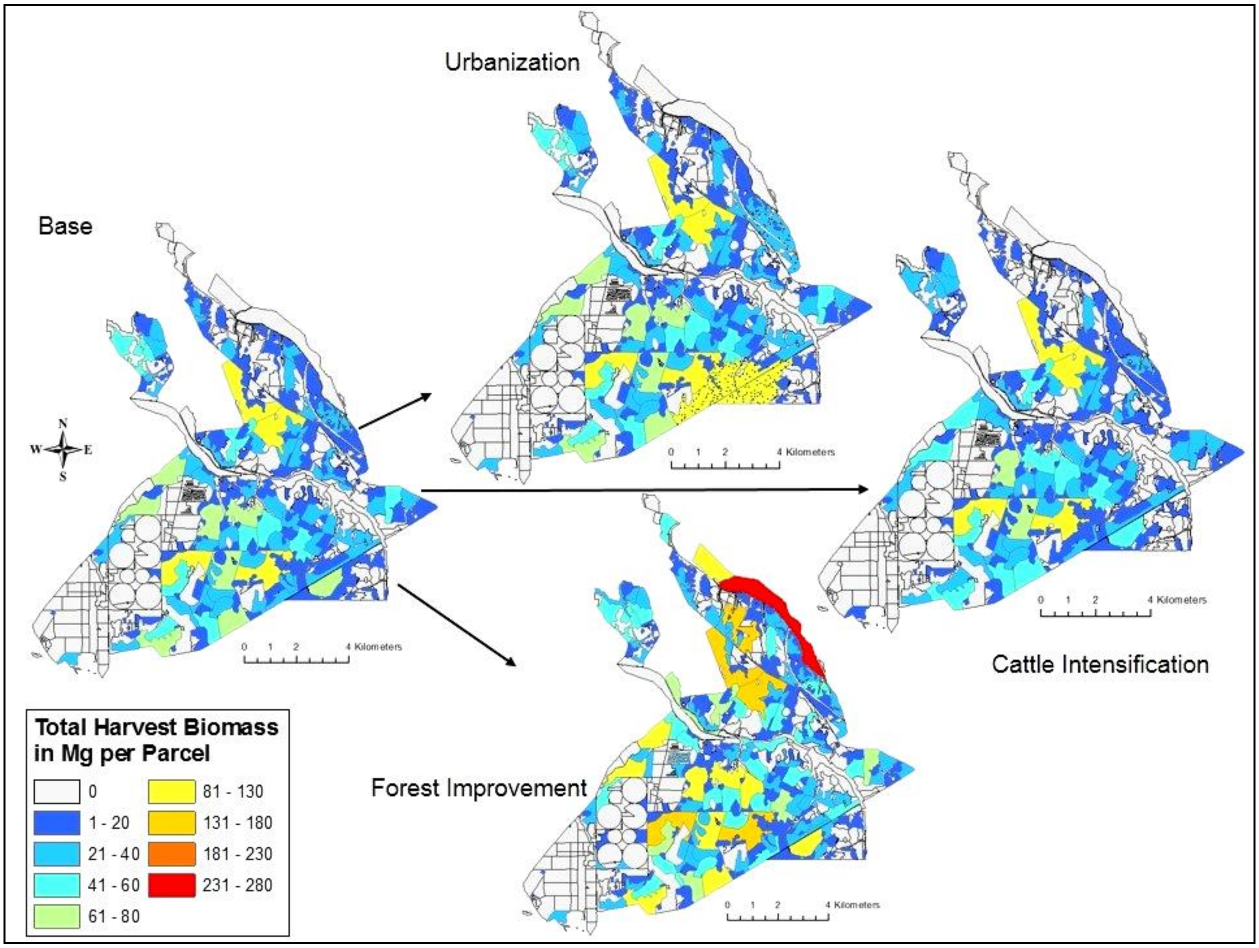

Figure 13: Total biomass per harvest parcel for each scenario. Grey areas symbolize zero value of harvested biomass. The highest values (231 Mg – 280 Mg) are dark red while the lowest values (1 Mg – 20 Mg) are dark blue. On the left is the base scenario functioning as a benchmark and on the right are the three future scenarios. *Urbanization* shows only little variations to the base scenario. There is a harvest reduction in the newly designated southern housing area (from light blue to dark blue). *Cattle Intensification* shows colder and darker colors than the base scenario, indicating a loss of biomass from harvestable products, e.g. larger parcels in the North from light green to turquoise. *Forest Improvement* is the only map displaying yellow, orange and red areas, showing that harvested biomass is highest in this scenario.

Base and *Urbanization* produce similar amounts and support a maximum of 130 Mg parcel^{-1} while *Forest Improvement* achieves up to 280 Mg parcel^{-1} biomass. These results can be explained by the increase in tree density, resulting in higher harvest rates with just a modest raise in harvest and management costs. Further, the area in the North-East of Charneca (see Figure 7 and Figure 13) which previously contained annual crops, is very large which results in high scores of Mg parcel^{-1}. *Cattle Intensification* shows less areas with medium harvest in contrast to the base scenario because many Montado parcels are transformed into pasture or annual cropland. Additionally, the high cattle-density results in a lower cork yield ha^{-1}, leading to lower harvest masses.

The trends observable in Figure 13 are reflected in the overall net present values (NPV) for the scenarios shown in Figure 14. *Forest Improvement* provides by far the highest economic value with EUR 3.35 million – almost 2.5 times as much value as the base scenario.

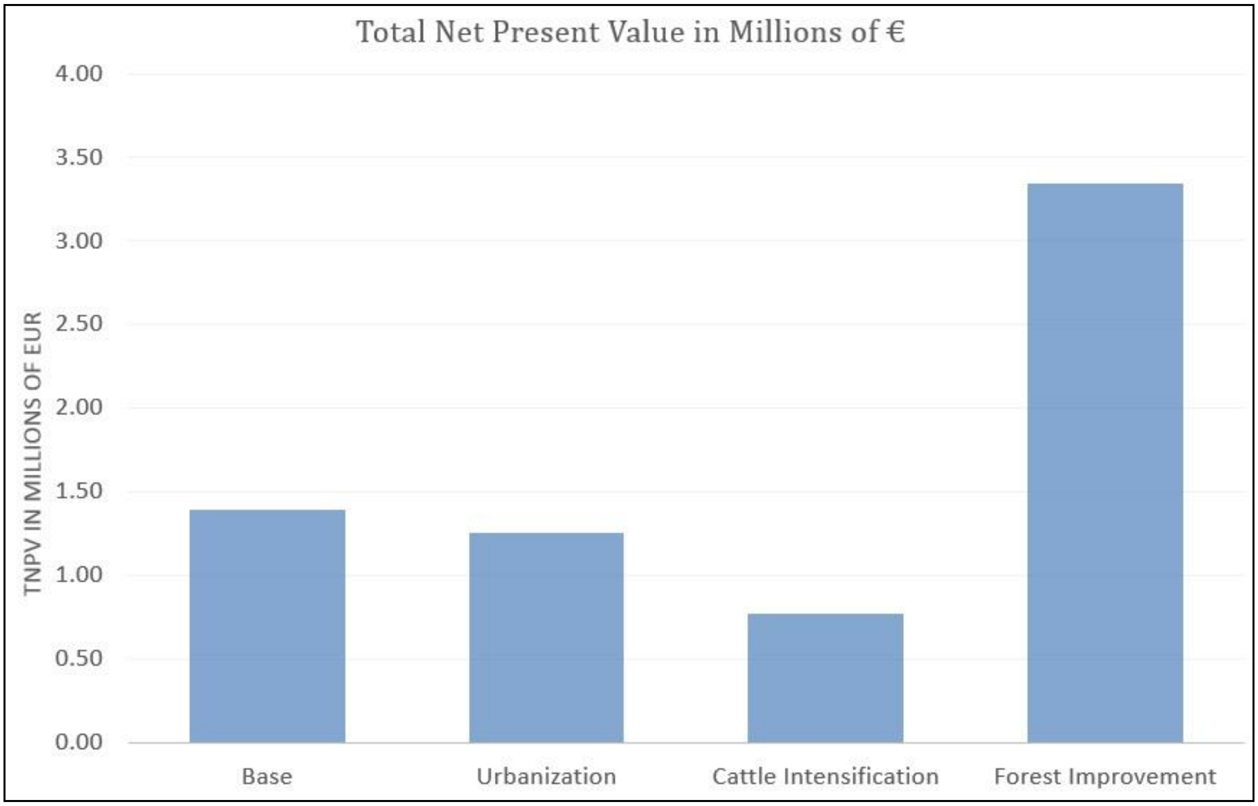

Figure 14: Total net present value of cork under base and future scenarios. The total value of *Urbanization* is slightly lower than the base while *Cattle Intensification* depicts a 50 % reduction in harvest value compared with the base. The difference between *Cattle Intensification* and *Forest Improvement* is significant with roughly EUR 2.5 million. *Urbanization* is the scenario with the lowest changes in absolute LULC and consequently is closest to the base scenario.

The timber model calculates values per parcel which are less representative since parcel sizes vary considerably. Therefore, I calculated the profits per hectare for each scenario and displayed them in Figure 15. I used averaged values for the model, thus each scenario supports only one profit ha^{-1} value with the exception of *Urbanization*, which has two values due to the designated residential areas.

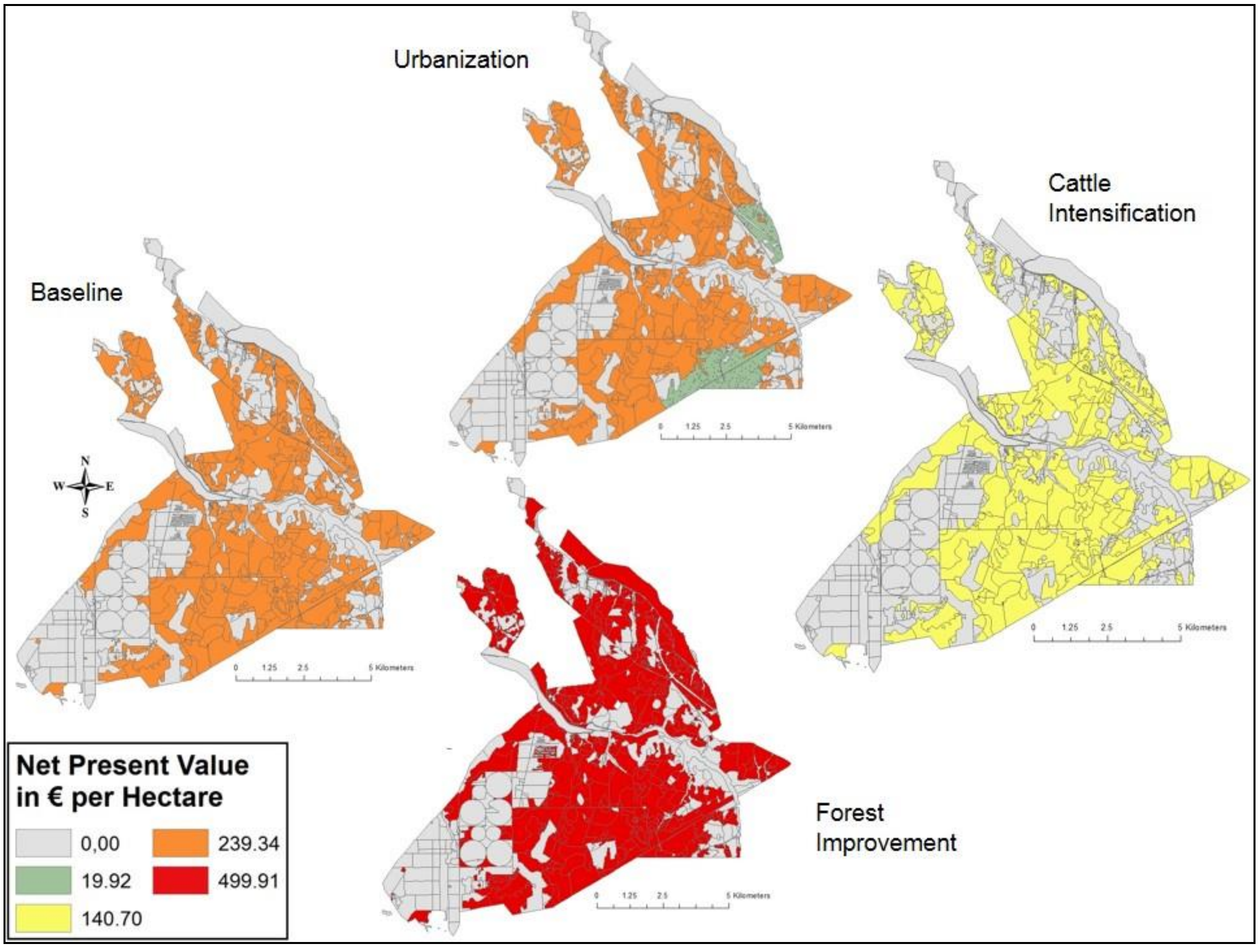

Figure 15: Cork harvest net present values in € per hectare. The left side contains the base scenario and shows the net present value of harvested cork in EUR ha^{-1} if no changes in LULC occurred. The value is EUR 239.34 ha^{-1}. *Urbanization* displays the same value for most of the area with the exception of the two parcel declared for housing which have a value of EUR 19.92 ha^{-1}. *Cattle Intensification* has lower overall value than base scenario, while *Forest Improvement* has the highest harvest value of almost EUR 500 ha^{-1}. Grey areas represent non-harvested parcels.

Figure 15 shows the NPV ha^{-1} for the base scenario and the future scenarios. *Forest Improvement* displays the highest value with almost 500 € ha^{-1}. Further, one can see which parcels have been converted from or to Montado for the respective scenarios visualized by their change in color (from or to grey). The total amount of harvestable parcels for *Forest Improvement* is observably larger than for the other scenarios.

5. Research Theme #2: Validity of ES Mapping

5.1. Setting

5.1.1. The Concept of Scientific Validity

If scientific research, experiments and tools want to be widely accepted they need to be designed in a way that enables them to produce valid outcomes (Trochim, 2006). According to Campbell & Stanley (1963) validity for research methods can be divided into internal and external validity. Internal validity refers to the logical soundness of a method and assesses the causal relations between its variables. External validity addresses the generalizability of its outcomes across "different types of persons, settings, and times" (Cook & Campbell, 1979, p. 37). Often those are regarded as being in a trade-off relationship, meaning that increasing one will lead to the reduction of the other (Jimenez-Buedo & Miller, 2010). However, this viewpoint has been challenged and several scholars see a more causal relation between the two stages, namely that internal validity can be regarded as a pre-requisite for external validity (Jimenez-Buedo & Miller, 2010; Trochim, 2006). Meaning, that unless "we ensure internal validity of an experiment, little, or rather nothing, can be said of the outside world" (Jimenez-Buedo & Miller, 2010, p. 302).

With regards to the idea of internal and external validity, I analyze ES mapping in general and the InVEST toolkit in particular in the following chapters. Bearing the causal relationship between internal and external validity in mind, I will conduct an internal validity analysis for the InVEST models applied in this thesis. Due to a lack of comparative studies, an external validity analysis of InVEST for my study area is not possible. Therefore, I will address the external validity of ES mapping in general by highlighting the inherent advantages (Chapter 5.1.2) and disadvantages of ES maps (Chapter 5.2.1.1). In Chapter 5.2.1.2 I analyze the existing literature focusing on comparative studies which address uncertainty and inaccuracy related to the use of ES maps.

5.1.2. Maps: Academia's Eye Candy

The concept of cartography, or mapmaking, is closely linked to the cognitive development of *Homo sapiens* (Lewis, 1987) and dates back to prehistoric times (Delano Smith, 1987). Despite being an ancient technique, maps still play a significant role in modern society and have long ago entered the realm of academia. Especially with the advancement of computer technology the scale and scope of mapmaking increased noticeably and possibilities of application are manifold (see Fox, Suryanata, Hershock, & Hadi Pramono, 2006; Whittaker et al., 2005).

Today, maps are an integral part of decision-making within environmental policy and are regarded as "powerful and influential applications within conservation biogeography" (Whittaker et al., 2005, p. 3). The explicit mention of ES maps in the EU Biodiversity Strategy to 2020 will further promote ES mapmaking (see European Commission, 2011, Target 2, Action 5). The implementation of maps within governmental directives is preceded by academic research and the applications of spatial tools. Leading projects and institutes in the field are the Natural Capital Project, IASS Potsdam, ARtificial Intelligence for Ecosystem Services (ARIES), Ecosystem Services Partnership and the OPERAs project (Egoh, Drakou, Dunbar, Maes, & Willemen, 2012).

Maps are seen as a useful tool for decision-makers; as shown by Hauck et al. (2013) who conducted interviews and a focus group discussion with policy-makers from national and regional levels to assess the role and potential of ES maps for policy. According to their findings, maps have an "air of authority" (Hauck et al., 2013, p. 28) for some of their participants and are frequently emphasized as a helpful tool for communication. Further, maps allow highlighting and illustrating complex circumstances in a compressed style and are able to visualize the consequences of specific policies (Hauck et al., 2013). Additionally, ES mapmaking enables identification of special areas of interests where several ES are provided simultaneously (Naidoo et al., 2008). Since the ES concept is closely related to the idea of trade-offs between different land-uses (Chan, Shaw, Cameron, Underwood, & Daily, 2006), maps can help to identify these in a spatial manner and provide the opportunity to make decisions based on a trade-off assessment as shown by Nelson et al. (2008) in the case of carbon sequestration and species conservation.

Next to these inherent benefits, maps can simply be visually appealing and allow the creator to display a landscape in an interesting and creative way. Further, maps are independent of language which increases accessibility. Thus, maps are an interesting vehicle to deliver information and can be a helpful tool to provide guidance for decision-makers.

5.2. Results RQ3 and RQ4: Validity of ES Mapping in General and the InVEST Toolkit

5.2.1. Research Question 3: Accuracy and Reliability of ES Mapping

5.2.1.1. The Dark Side of the Map

After quantifying two ES for the Montado (Chapter 4.2) and having demonstrated the benefits of mapping ES (Chapter 5.1.2), I now turn towards exploring some of the drawbacks of ES mapping in general based on a literature review to analyze their accuracy and reliability (RQ3). These include reliance on proxies, mismatch of scales, and decisions of the map creator.

Because not all ES can be measured directly, ES mapping often relies on the use of proxy methods which can introduce uncertainty. Proxy methods "use indicators, derived from land use or land cover as a proxy for the provision of ES" (Pagella & Sinclair, 2014, p. 387). A common example is climate regulation services, because they are not expressed in explicit climate variables, but use factors explaining climatic variations (Crossman et al., 2013). I used carbon pools in the Montado to map the provision of climate regulation services. Thus, carbon pools are proxies and do not explicitly represent a climate variable. Proxy methods are frequently used to define ES (Eigenbrod et al., 2010), because primary data often are hard to obtain and come at high costs (Plummer, 2009). In the absence of primary data, models based on secondary data or land-cover proxies are most frequently employed (Eigenbrod et al., 2010). For example, Eigenbrod et al. (2010) refer to global valuation of nutrient cycling which is based on a single case study from India. Egoh et al. (2012) found that 70 % of published studies used proxies to quantify the addressed ES, whereas only 13 % of the ES have been quantified using primary data.[9] A similar literature review conducted by Martínez-Harms & Balvanera (2012) confirms these findings, as it found 59 % of the reviewed papers to use secondary data for ES mapping. Another problem of using proxy methods is the stigmatization of regions (Hauck et al., 2013); as each cell of a map is assigned a specific LULC class, some cells comprise several LULC classes but only one is visible. This potentially distorts the map and alienates it from the actual land-cover characteristics which might be more heterogeneous.

Another difficulty is mismatch of scales. ES appear at scales that do not align with the scales of decision-making (Hauck et al., 2013). For example, pollination is often dependent on suitable micro-habitats for bees. Hence, efforts to provide this habitat happen on scales much smaller than the ones decision-making takes place at. Another issue closely connected to this, is the question of resolution. How fine or coarse should a map be to address the respective objective the best way possible? Choosing a certain resolution for a specific ES often implies the negligence of a different ES in the same region, for example "[s]ynergies between ecosystem services perceived at a watershed scale may not reflect specific trade-offs observed at the local scale" (Hauck et al., 2013, p. 28). Furthermore, Konarska et al. (2002) investigated the influence of resolution on the valuation of ES and found that results vary significantly. They showed that a finer resolution of 30 m led to ES value estimations twice as high in comparison with a coarser resolution of 1 km.

The final difficulty includes decisions made by the map creator, for example the grid size, the choice of ES or the resolution of the map. Map creators are in a position of power and therefore play a significant role in the process (Hauck et al., 2013). They determine the area of interest, which features to include, which features to exclude, the color scheme, the symbology, and the LULC classes used. Therefore, intentions and objectives need to be transparent from the beginning and ideally be aligned with estimations and opinions of stakeholders, decision-makers and experts.

5.2.1.2. Ecosystem Service Maps in Practice: Comparing Results

The three inherent shortcomings of ES mapping (see Chapter 5.2.1.1) are empirically confirmed by two studies. The first study compared the use of primary data to secondary data while the second study compared the results of different ES mapping tools.

[9] Egoh et al. (2012) conducted a literature review which encompasses 67 publications between 1997 and 2011 containing mapped or modelled ES.

With regards to the issue of using proxies in the absence of sufficient primary data, Eigenbrod et al. (2010) conducted an England-wide study. Their aim was to examine "the effects of using proxies on ecosystem service maps and the degree of spatial congruence of these maps with primary data" (Eigenbrod et al., 2010, p. 377). For the study three ES have been assessed, namely biodiversity[10], carbon, and recreation. Their results imply that "distribution maps based on proxies provide poor estimates of the distributions of ecosystem services based on primary data, with the proxy distributions at best only very broadly similar to maps based on primary data" (Eigenbrod et al., 2010, p. 380). The highest correlation (Spearman's *rho*[11] = 0.57) was found for carbon storage models, followed by recreation (0.5) and biodiversity (0.37). Further, the results proved to be highly inaccurate for identifying areas where several ES appear simultaneously, so called ES hotspots. Overall, Eigenbrod et al. (2010) conclude that proxy-based ES maps have a poor fit to actual data.

The second study conducted by Schulp et al. (2014) addresses the question how different ES mapping tools compare to each other regarding output quality and comparability. Their focus lies on generating "insights in the uncertainty of ecosystem service maps and discuss the possibilities for quantitative validation" (Schulp et al., 2014, p. 1). The study systematically compares ES maps of Europe and identifies spatial patterns of agreement or disagreement for five ES.[12] While for some ES (e.g. recreation and climate regulation) the tested maps produce high similarities and show an overall agreement of ES locations, other services (e.g. erosion protection) exhibit high discrepancies (Schulp et al., 2014). Especially, the identification of coldspots and hotspots produced large errors. For erosion protection "maps disagree in half of the area considered, meaning that in half of the EU territory some maps expect a hotspot for erosion protection while other maps expect a coldspot at the same location" (Schulp et al., 2014, p. 5).

Both papers conclude that the quality of ES mapping largely depends on the services that are addressed, the availability of primary data and the consistency in methodology. Further, ES maps are particularly prone to error when looking for ES hotspots.

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[10] There is an ongoing discussion in the scientific community whether biodiversity should be regarded as a final ecosystem service or as a supporting prerequisite for other ecosystem services.

[11] Spearman's *rho* is a correlation coefficient that describes the relationship between two variables with a monotonic function valued between 0 – 1. The value of 0.57 is not regarded as 'especially high' by Eigenbrod et al.

[12] Climate regulation, flood regulation, erosion protection, pollination, and recreation

5.2.2. *Research Question 4: Testing InVEST's Internal Validity*

5.2.2.1. *Carbon – Model Analysis*

In order to explore the validity and precision of the InVEST toolkit (RQ4) I analyze the two models used in this thesis. Figure 16 shows the total amount of input variables needed for running the carbon and timber InVEST models. Carbon requires a total of 20 inputs, of which eight each are ranked with medium and high certainty and four with low certainty.

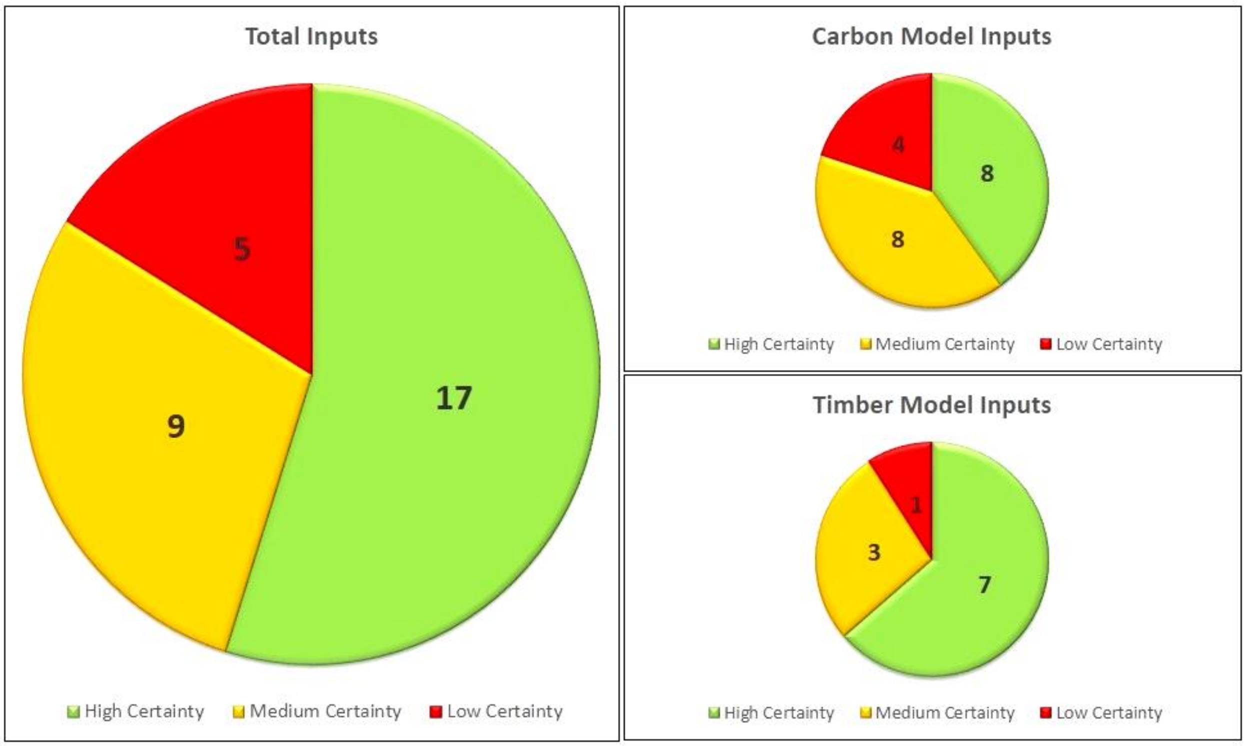

Figure 16: Certainty ranking overview for the InVEST model inputs. Green coloring represents an input which is ranked with high certainty, yellow medium and red low certainty. The left pie chart shows the total amount of input variables used for the timber and the carbon model combined (the recreation model is not included, see Chapter 4.2.1). The left charts show the quantities for each of the models. High certainty input dominate with 17 out of 31, followed by medium certainty (9 / 31) and low certainty (5 / 31).

The distribution of certainties within the internal structure of the model is shown in Figure 17 and depicted by the small circular symbols. The figure shows that spatial information is highly certain which is due to the detailed mapping of the study area by the research team from the University of Lisbon. One key element of the model, namely carbon pools, shows medium certainties. This can be explained by a lack of primary data on carbon contents for the study area. Some of the values have been calculated for Portugal specifically whereas others have more general character. Especially, the soil carbon values are uncertain as the values for podzol soils[13] are based on a study conducted in the Czech Republic (Freyerová & Šefrna, 2014).

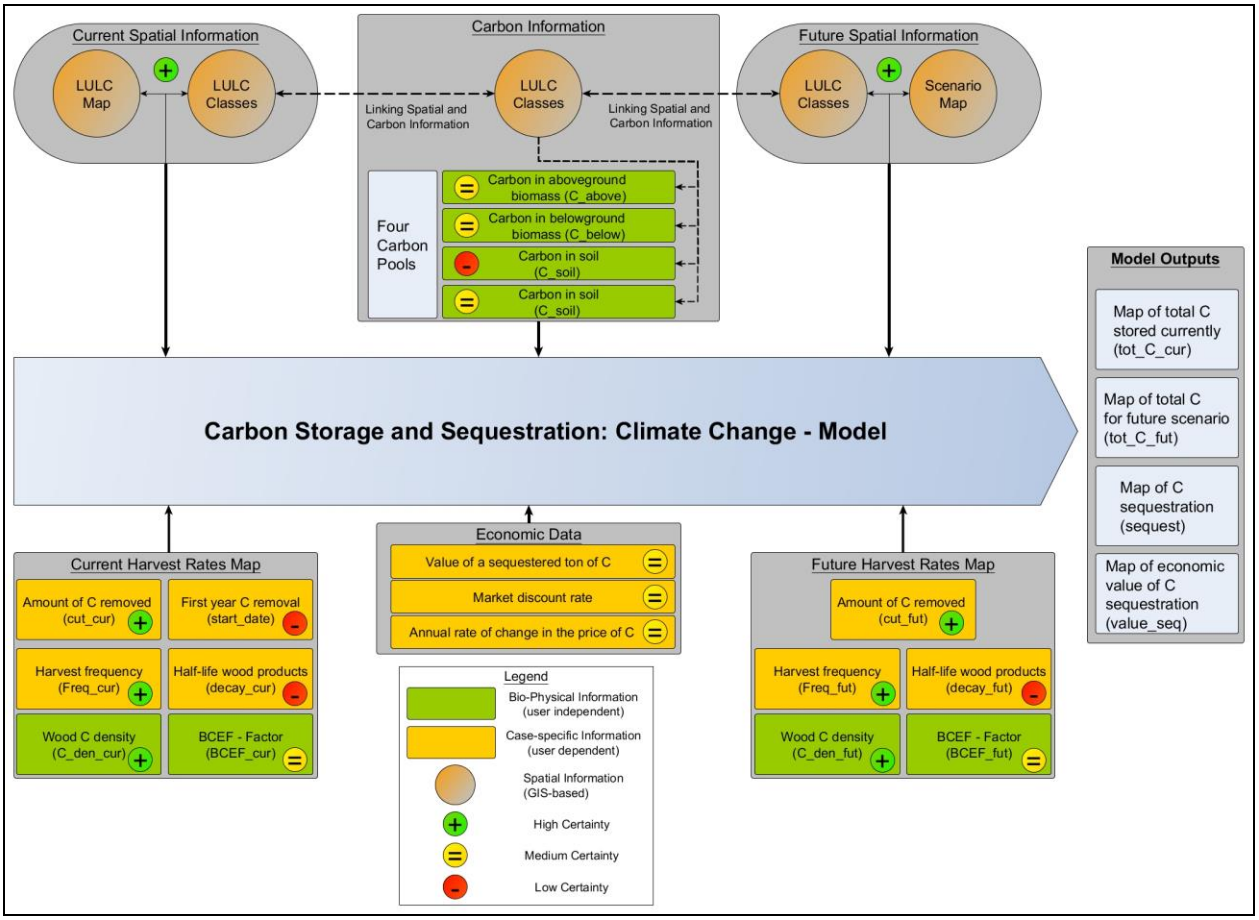

Figure 17: Visualization of the carbon model with certainty ranking. The flowchart diagram represents the functioning and structure of the InVEST carbon model. Spatial data is represented by circles, bio-physical information by green boxes, and case-specific information by yellow boxes. Green, yellow and red dots represent the certainties respectively (see Figure 16). The distinction between bio-physical and case-specific input variables is fuzzy at times, because some input variables belong to both categories (e.g. carbon density of wood is bio-physical, but the specific tree species depends on the case study). The diagram shows only the options (and inputs) I employed to run the model.

The input values for the economic valuation of CSS are of medium certainty. This is mainly due to the overall uncertainty of carbon values on the market. Carbon prices proofed to be volatile since emission trading began in the early 2000's (Kossoy & Guigon, 2012). The case of carbon is particularly interesting as its future value is very dependent on the development of our climate and society. For example, if by 2040 we surpass critical thresholds of carbon in our atmosphere and global temperature has risen

[13] Podzols account for 70 % of the study area's soil type.

significantly, sequestering additional carbon at that point of time will only have little value for society (Sharp et al., 2014).

Cork Products bear another source of uncertainty: the half-life of wood products. Obtaining reliable numbers for the half-life of cork products proofed to be impossible as it is highly dependent on local waste management. Portuguese cork stoppers are exported all over the world and there are no statistics on what happens to stoppers after their usage. Including Cork Products is an optional feature of InVEST, thus running the model twice – with and without Cork Products – allows to determine the influence of the feature.

On the contrary, other input values can be predicted with a high certainty. The amount of carbon removed, harvest cycles, and wood carbon density are well-document and can be stated precisely. When running the base version of the model (excluding Cork Products and economic valuation) the only uncertain variable is the soil carbon content. Bearing in mind that this is one out of four carbon pools and the value remains for all future scenarios, the base version of the model will provide sound carbon storage and sequestration outputs. The absolute values might not fully represent reality, but the relative changes for each scenario are precise and consistent.

If users want to employ the optional features uncertainty will increase as the input values bear uncertainty. Running the model with current and future harvest rate maps plus the economic valuation would add three low certainty and medium certainty variables to the equation. Especially, financial valuation can differ significantly from reality considering the potential errors of total and sequestered carbon outputs plus the uncertainties connected to financial valuation of carbon in general.

5.2.2.2. Timber – Model Analysis

As shown in Figure 16 the total number of input variables is eleven with seven being highly certain, three of medium and one of low certainty. Figure 18 shows the structure of the model and the distribution of the variable within this structure. Since the timber model predicts the financial value of the study area the statement regarding the validity of the economic valuation of the carbon model holds true for the timber model, too.

The only uncertain variable for this model is maintenance costs. Despite the availability of detailed financial data for Companhia das Lezírias, it is very difficult to make a precise statement about the costs. According to Rui Alvez[14] it is impossible to determine a single, realistic value for the maintenance costs of

[14] Rui Alvez is the forest manager of Companhia das Lezírias.

one hectare of Montado. This is mainly because much of the work is not exclusively done for the Montado but affects other LULC classes as well. Further, administrative, seasonal and extraordinary costs cannot be attributed to a specific land-cover type and therefore produce a distorted picture (R. Alvez, personal communication, March 02, 2015).

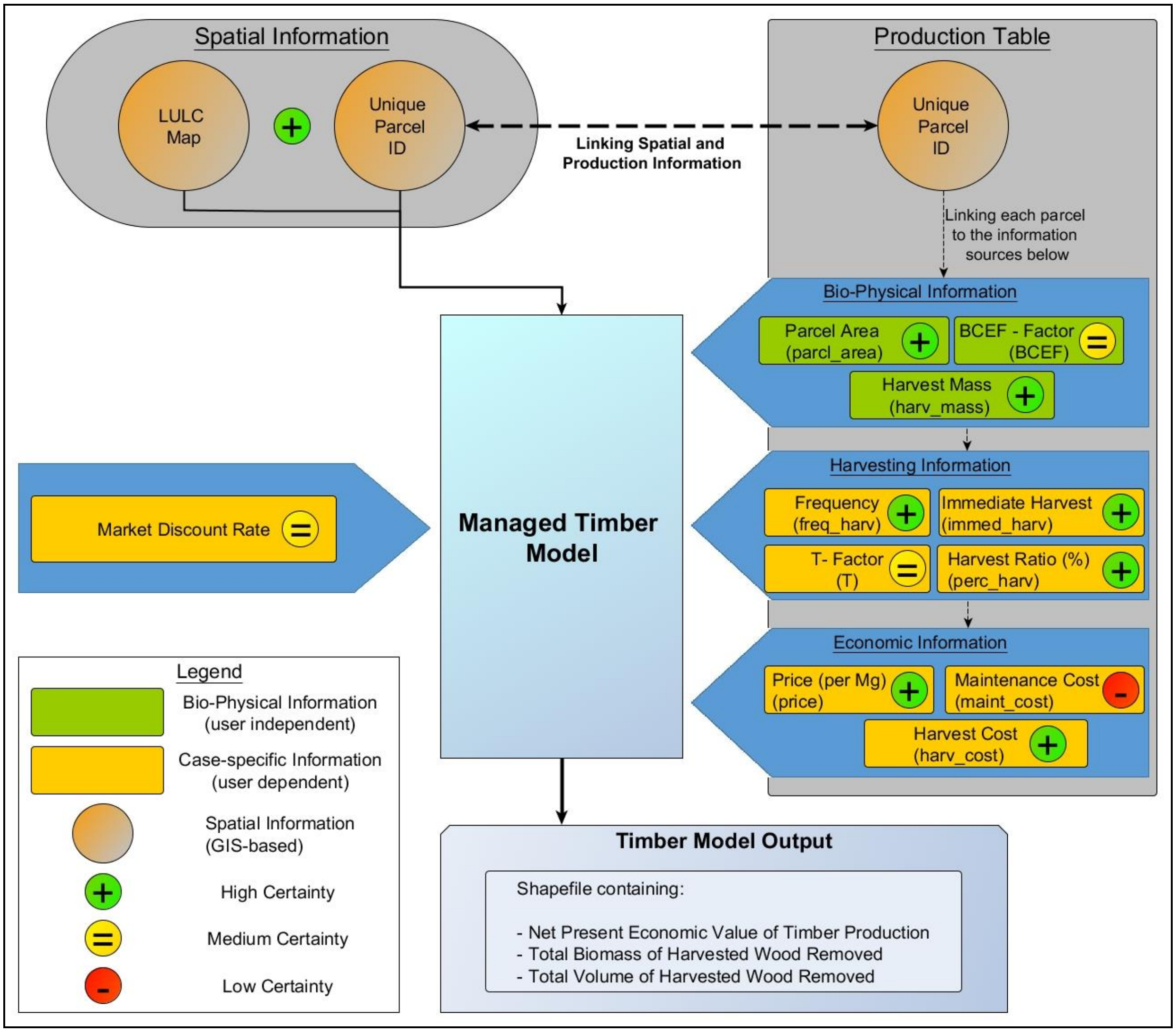

Figure 18: Visualization of the timber model with certainty ranking. The flowchart diagram represents the functioning and structure of the InVEST timber model. Spatial data is represented by circles, bio-physical information by green boxes, and case-specific information by yellow boxes. Green, yellow and red dots represent the certainties respectively (see Figure 16). The visualization represent the full functioning of the model and includes all data inputs.

Overall, the data certainty of the timber model is higher than for the carbon model. At the same time, the timber model has less optional features and therefore the low certainty of maintenance costs remains in the model. Since the profit of a harvest parcel is calculated by subtracting the costs from the revenues, this variable has noticeable impact on the results. Although this variable is case specific, obtaining a precise number could also be complicated in other cases studies. Similar to the carbon model the timber model provides a good opportunity to compare the harvest performance under different future scenarios.

5.2.2.3. General Experiences Using InVEST

My general experiences showed that InVEST is a decently accessible tool with a high degree of internal transparency and a helpful community to get the user started. Problems may occur when communicating with stakeholders who are unfamiliar with the tool or who believe that the data inputs required for InVEST are not appropriate for the context.

Accessibility

InVEST is free of charge and standalone open source software which allows users to access the tool without financial restrictions. However, in order to prepare inputs and view and edit outputs, further software is required – InVEST is practically useless without a geographic information system (GIS). Further, a spreadsheet application is required to prepare input. It is also helpful to have some very basic image editing software to prepare, crop and edit the outputs generated by InVEST.[15]

Besides the technical aspect, accessibility also refers to the ease of using the tool both for users and stakeholders. The user's ability to access InVEST depends on previous knowledge, general experience in using computer technology and availability of time. Personally, I can say that with sufficient time, determination and basic software skills it is possible to understand, run and interpret the tool.

Data Alignment

Scenario development should happen in cooperation with local stakeholders to profit from their knowledge and experience. In my case stakeholders were the colleagues at the University of Lisbon and the forest manager of Companhia. While the University staff is well-trained in spatial modelling and easily grasped the concept of InVEST, collaborating with Rui Alvez from Companhia proved to be slightly more difficult although he is trained in GIS software and forest management. InVEST requires certain abstractions and averaged data which is contrary to what R. Alvez is used to working with and which is sometimes simply not available. For example, when one of my colleagues asked for an average tree circumference, the answer was that there is no average value because it depends too much on the location of the stand, the average age of the trees, and the soil type. The lack of averaged values poses as an obstacle for users of InVEST, especially when working with large study areas.

[15] All software required to run InVEST can be obtained free of charge.

Transparency

Natural Capital Project (NatCap) provides a comprehensive user guide which describes the functioning of each model, the required data and which optional feature each model provides and how they alter the results. The level of detail is high and includes formulas and equations underlying the models. Additionally, the user guide provides a section addressing the limitations and weaknesses for each model and the level of detail in general.

Although the internal transparency is good, to my knowledge there is no external review addressing the accessibility and transparency of InVEST. Hence, the only sources employed here to evaluate the tool are the NatCap documents and my own experiences using InVEST.

User-friendliness

As abovementioned, InVEST requires GIS and spreadsheet applications to use its full potential. Basic spreadsheet knowledge of functions, equations and formulas (such as VLOOKUP in excel) are helpful and reduce preparation time.

According to NatCap, running InVEST effectively “does require basic to intermediate skills in ArcGIS” (The Natural Capital Project, 2015 "Technical Specifications"). In order to prepare the input maps, create scenarios, view the outputs, and edit them into a presentable format, GIS software is indispensable. Successfully completing these tasks without previous knowledge requires time and autodidactic abilities, especially since InVEST does not provide guidance for other tools.

A great help is the NatCap forum where users can seek help from other users and developers of InVEST. The response times are good and answers are detailed and helpful.

6. Discussion

6.1. RT-Mapping: Mapping ES in the Montado – Insights for Decision-Making

In order to answer the overall RQ how ES mapping can contribute to landscape conservation and what the constraints of this approach are, I summarize and interpret my findings for the two research themes.

Cultural Ecosystem Service – Recreation

The recreation model did not produce significant results, but relevant literature suggests that Montados are of high cultural value nonetheless. Several authors, including Surová et al. (2011), Regato (2007), Pereira & Tomé (2004), and Pinto-Correia (2011) mention the high recreational and cultural value of the landscape. In 2011 the Portuguese parliament unanimously recognized the cork oak as a national symbol of the country, granting it the same status as the flag and the national anthem (Louro, Monteiro, Constantino, & Rego, 2014), thus highlighting the cultural importance of the species.

Regulating Ecosystem Service – Carbon

The results show that the LULC classes with the highest storage and sequestration values are mixed forests and Montado with dense shrub understory, followed by the remaining three types of Montado landscape (Figure 11). Including Cork Products in the model further increases the sequestration value as carbon remains stored in the cork products for several years. These findings are confirmed by the scenario analysis, with *Forest Improvement* displaying the highest carbon storage potential and *Cattle Intensification* scoring lowest. Transforming more land into intact Montado would help to sequester additional 80 Gg carbon until 2050. Following the *Cattle Intensification* scenario, however, would lead to a net release of carbon from the landscape into the atmosphere of almost 40 Gg. Not factoring in the additional emissions caused by the higher number of animals. Considering that cork oak savannahs cover almost 2 million ha in the Mediterranean (Pereira & Tomé, 2004; Pinto-Correia et al., 2011) the effects of applying conservation policies on a larger scale are significant.

The valuation results estimate the total value of sequestration for *Forest Improvement* to be USD 2 million and a total value loss of USD 1.15 million for Cattle Improvement. Monetary valuation is of high interest for decision-makers as it allows for comparisons between land-use options using a single unit (Gómez-Baggethun et al., 2010). In addition to the inherent problem of monetary valuation (see Chapters 5.2.2 and 6.3) the uncertainty analysis of the carbon model shows low and medium certainty for economic data input (see Figure 17). Hence, the potential for error is high and the estimated values may vary significantly from real values. But, even if the absolute numbers are likely to differ from reality, the relative changes between the different scenarios remain valid and can be helpful information for decision-making: values for CSS under *Forest Improvement* are clearly positive whereas *Cattle Intensification* will lead to a loss in sequestration value.

Provisioning Ecosystem Service – Timber

The result from the timber model show similar trends to the carbon model, namely that ES provision is highest under *Forest Improvement* and lowest under *Cattle Intensification* (Figure 13 and Figure 14). The uncertainty distribution for the timber model (Figure 18) reveals comparatively certain inputs for the biophysical and harvesting information, resulting in relatively sound outputs. The results show that managing the landscape for *Forest Improvement* would increase cork harvest, while intensifying cattle cultivation would reduce it respectively.

According to the monetary valuation generated by InVEST *Forest Improvement* would generate profits of EUR 3.35 million until 2050, while *Urbanization* and *Cattle Intensification* generate EUR 1.25 million and EUR 0.77 million respectively (Figure 14). These values need to be viewed with caution due to the low certainty for maintenance cost and medium certainty for market discount rate (Figure 18). The maintenance costs are central to the results since profit is calculated by subtracting costs from revenues. Another aspect when analyzing the financial value of the ES are opportunity costs. Transferring pasture into Montado will increase the cork yield, but it will decrease profits from livestock farming. The valuation results are of interest for decision-makers particularly looking at the relative changes between the scenarios and as a reminder to factor ES in their decision-making.

Synopsis

The Montado landscape provides ES on both local and global scales. Harvesting cork is a Provisioning service and important for the livelihood of landowners and processing industry on local and regional scales (APCOR, 2014). Storing and sequestering carbon is a Regulating & Maintenance service and contributes to climate regulation on a global scale (IPCC, 2014). Literature reviews and the InVEST generated outputs show that an intact Montado landscape provides higher Provisioning and Regulating & Maintenance services than any other LULC class included in this study.

I found that for *Forest Improvement* comparatively small changes in land management can have major implications for the productivity of the landscape. A change in LULC of 15 % of the area accompanied by an increase in tree density from 80 to 140 trees ha^{-1} lead to an increase in harvested biomass of 61 % until 2050 compared to the base scenario (see Appendix C). The *Cattle Intensification* scenario, however, requires around 60 % of the area to undergo changes in LULC. The result is an increase of cattle head of 50 % but overall reductions in harvest productivity and ES provision. This suggest that small adjustments towards a more traditional Montado landscape can result in significant improvement in ES provision. Thus, both the costs to change the LULC and the loss or gain in ES should be factored in by decision-makers for future land management planning.

The decision for or against a certain land management option is very case specific and requires meticulous information and planning. The results from this study highlight that ES provision should be accounted for when thinking about the future of the Montados. Especially, when calculating trade-offs and conducting cost-benefit-analyses, ES could tip the scale towards traditional management option. Companhia das Lezírias, being the largest single-handedly owned property and under public control could function as an important exemplar for other land-owners in Portugal and the whole Mediterranean.

Portugal is an EU-member and subject to the EU 2020 Climate and Energy Package, which includes a 20 % reduction of GHG-emissions by 2020 (base year 1990, European Commission, 2009). Improving the existing Montado landscape and thereby the CSS potential can help to achieve these goals. The same holds true for the EU Biodiversity Strategy to 2020 since the Montados are a highly biodiverse landscape and protecting their traditional character will help to reach these targets.

6.2. RT-Validity: Validity of ES Mapping – Implications for Sustainability Science, the ES Concept and Conservation

The findings of this thesis provide new insights for several topics under the sustainability science umbrella: transferability of ES mapping results, a contribution to the ongoing debate between traditional and modern conservationists, the validity of ES mapping tools, and the use of secondary data.

Transferability or generalizability means the extent to which stakeholders can facilitate one ES to plan for another. Available studies show a certain level of discrepancy in their findings. For example, Egoh et al. (2008) found that “weak correlations between ecosystem services assessed in this study and in Chan et al. (2006) demonstrate that one cannot use one ecosystem service to plan for others” (p. 139). Slightly different are the findings from Nelson et al. (2009) and Polasky et al. (2011), who saw little evidence for tradeoffs between ES and biodiversity conservation and found that certain conservation scenarios also benefit other ES.

The results from this thesis suggest a similar trend as both CSS and cork production increase under the same scenarios. It is worth mentioning, though, that CSS and cork production are naturally closely related and are unlikely to differ under similar land management models. Another ES that seems to be improved by an intact Montado landscape is watershed conservation (Bugalho & Silva, 2014).[16] Overall, these findings suggest a positive correlation between the provisioning of different ES. However, the previously mentioned papers sound a note of caution. Ecosystems are highly complex and unique so that generalizations should not lead to decision-makings without further investigation (Plummer, 2009).

Seeking answers to RQ3 (see Chapter 5.2.1) produced that ES maps can be prone to inaccuracy due to the frequent reliance on proxy methods, mismatch of scales and subjective decisions by map-makers (Eigenbrod et al., 2010; Schulp et al., 2014). These results will add further fuel to the debate between traditional and modern conservation approaches (Chapter 2.1.2) because they question the reliability of a core component of the ES concept: ES mapping. My findings support the traditional section which is skeptical towards the utilization of ES for human well-being. If future studies confirm these first findings,

[16] See: The Green Heart of Cork, http://d2ouvy59p0dg6k.cloudfront.net/downloads/ghocenglish.pdf

ES mapping will be employed more cautiously and ideally more precise. However, this also entails the risk that the reputation of ES maps in general suffers which may lead to a universal skepticism among decision-makers. Thus, it becomes even more important to be transparent about the mapping processes and to communicate the limitations and shortcomings openly.

In order to answer RQ4 I analyzed the internal structure and the case-specific input variables for InVEST (see Chapter 5.2.2.). My findings suggest that the validity of InVEST largely depends on data availability which is closely geared towards to the study area and to the resources the user has access to. Further, choices of spatial resolution, temporal scales, scenario composition, and stakeholder involvement play an important part in the modeling process and can have high impact on the final results. This emphasizes the need for transparent documentation of data inputs and disclosure of limits and uncertainties connected to the modelling process in order to generate results which can be fully understood and interpreted by the recipient.

Eigenbrod et al. raise the questions whether we should make decisions based on incomplete or imprecise estimates from proxy-based ES maps (2010, p. 383)? The findings of this study can contribute to the debate by providing more results and experiences from ES mapping tools. Although proxy-based models are less precise and likely to differ from reality, they can still add value to this field of research by illustrating the needs for primary data (Lautenbach, Kugel, Lausch, & Seppelt, 2011) and by functioning as a benchmark for further studies (see Schulp et al., 2014). Further, the growing body of critical literature raises awareness about the accuracy problems of ES maps among the users inducing a more cautious application of results.

Another question is, if the lower costs of secondary data outweigh the costs of potentially inaccurate maps which might lead to misevaluation and wrong identification of high value areas (Plummer, 2009). Eigenbrod et al. argue that the investment in sound data acquisition for ES mapping "will far outweigh the costs" (2010, pp. 383 - 384). Conducting this was only possible due to the use of proxy methods and secondary. I like to believe that despite the uncertainty connected to proxy methods and secondary data this thesis is a valuable contribution to ES mapping research and sustainability science as a whole.

6.3. Limitations and Simplifications

Mapping ES in the Montado landscape inevitably includes limitations and simplifications which can be separated into two levels, namely ES mapping in general, and specific limitations of the InVEST models. Shortcomings of ES maps are addressed in detail in Chapter 5.2.1. and include problems of primary data availability (Eigenbrod et al., 2010), spatial resolution (Konarska et al., 2002), usage of proxies (Egoh et al., 2012), subjectivity of the map creator (Hauck et al., 2013), and seemingly contradictory results from different mapping tools (Schulp et al., 2014). These aspects are not limited to specific cases, but rather apply to ES maps in general (Martinez-Harms & Balvanera, 2012), hence should be communicated and accounted for when used to inform decision-makers (Hauck et al., 2013).

The carbon model assumes that the carbon content for each LULC class remains stable over time. This means that unless cells change LULC class or Cork Products, the sequestration value will be zero, not accounting for naturally occurring succession of the vegetation (Sharp et al., 2014). Another limitation of the carbon model is its reliance on the carbon estimates for specific LULC classes. Meaning, the results can only be as detailed as the LULC classes used to generate them (Sharp et al., 2014). Considering the complexity and heterogeneous character of the Montados, the carbon estimates might vary considerably within a single LULC classes and do not account for natural variations. For the Cork Products, InVEST only calculates one harvest rate and one decay rate. In the case of cork, the products' lifecycles vary significantly. For example, a cork stopper might be incinerated right after being removed from the bottle and has a lifetime of well below a year. Contrary, cork for in-house insulation would remain in use for several decades and have a much longer lifetime, thereby contributing to the overall carbon storage. Additionally, carbon emissions of harvesting and processing activities are not considered.

The major limitation of the timber model is that it fails to account for variations of the input variables over time. Thereby, the model neglects disturbances such as wildfires, droughts, or poor harvests. Further, the model uses several mean values per hectare, including price of timber, harvest mass, harvest cost, or maintenance cost. When looking at the whole area, the averaged values will produce results close to reality, but also distort the spatial distribution and reduce the level of detail of the output map.

One general consideration to be made is the scale of the study area. Although InVEST technically processes all scales, users need to review if their desired study area makes sense for the respective model. The studies using InVEST range considerably in area: from 1,000 – 10,000 ha up to 550,000 km^2 (B. Fisher et al., 2011; Goldstein et al., 2012). Charneca, with 11,000 ha is on the lower end of the spectrum. According to my own experiences, this size is most likely too small to reliably apply the recreation model, as Flickr-images may be scarce and precision and intention of the user taking the photo is questionable. The size of the study area also influences the level of detail for LULC classes and the explanatory power of the results. For example, making abstractions and generalization for a very small study area is likely to neglect important information and results could be distorted. On the contrary, choosing a large study area will require the user to generalize input information and make abstractions. Otherwise, obtaining the required detailed information for a large study area is very challenging and the amount of data will be hard to handle and interpret.

7. Conclusion and Outlook

The aim of this thesis was to explore ES under different future scenarios in the Montado landscape with a special emphasis on spatial mapping of ES and its scientific validity. I focused on Provisioning and Regulating & Maintenance ES under three LULC scenarios in Charneca for the year 2050. In order to investigate the scientific validity of the ES mapping approach in general and the InVEST toolkit in particular, I reviewed current literature about ES mapping and conducted an internal validity analysis of two InVEST models.

My results illustrate that an intact and traditionally managed Montado landscape provides a higher degree of Provisioning and Regulating & Maintenance services than alternative land uses, such as farmland, monocultures, pastures or shrubs. Further, the future scenario aiming for an improved Montado landscape with higher tree densities and less pressure through cattle grazing (*Forest Improvement)* scores the highest results for both ES (see Chapter 4.2). On the contrary, *Cattle Intensification* with reduced Montado area and higher grazing pressure underperformed with regards to the ES. *Urbanization*, which comprises a moderate land-use change towards residential areas has the least effects on Provisioning and Regulating & Maintenance services and is close to the base scenario.

A review of the existing literature produced that maps have certain inherent benefits and shortcomings and therefore need to be assessed and used attentively (Hauck et al., 2013). With regards to ES maps current literature revealed that tools frequently use secondary data or data proxies instead of primary data (Egoh et al., 2012; Martinez-Harms & Balvanera, 2012) creating room for errors and likely to move results away from reality (see Chapter 5.3, Eigenbrod et al., 2010). The question of InVEST’s internal and external validity cannot be finally clarified without comparing results to other tools and to outputs generated though primary data. However, my analysis shows that data availability is an important factor for InVEST’s validity and therefore is highly case and user specific. With access to resources and good overall data availability, InVEST is a helpful tool for ES mapping and scenario analysis in particular (see Chapter 5.2.2).

One thing to bear in mind beyond the discussion about quantification of ES and validity of mapping is that “ecosystem services provide an important portion of the total contribution to human welfare on this planet” (Costanza et al., 1997, p. 259) and therefore require as much attention and protection as possible.

The updated planetary boundary approach by Steffen et al. (2015) shows the critical development of the nine planetary systems and underlines the urgency to take action if we want to preserve current climatic conditions and the vital ecosystem services that come with it. The rate of biodiversity loss is critically high and the boundaries for genetic diversity have already been crossed (Rockström et al., 2009; Steffen et al., 2015). This emphasizes the role of ES as part of conservation science, particularly considering that ecological tipping points are unknown and the critical amount of species loss is unpredictable (Rockström et al., 2009). Therefore, sustainability scientists need to keep urgency and uncertainty in mind and join forces on solutions for global biodiversity loss. I think seeking new opportunities to promote conservation is a legitimate approach and should be investigated, considered and pondered carefully. If it turns out that these new approaches are ineffective, imprecise or in the worst case even counter-productive we should not follow them and rather focus on traditional values or seek other options.

Personally, I wish for a world in which conservation for nature's sake is not even a point of discussion. In particular, because natural values and wonders go far beyond everything quantifiable and measurable. It should be an inherent desire of every human being to protect nature's values. Unfortunately, not everyone is in the same, comfortable position to make such a claim, and others just do not share this enthusiasm. The rate of environmental degradation over the past decades (Millennium Ecosystem Assessment, 2005b) shows that relying in humanity's enlightenment about nature conservation is gambling at high stakes. Ecosystem service mapping, if used with caution and awareness of its limitations, provides one opportunity to promote ecosystem conservation. It may not be the silver bullet to environmental problems, but it is one piece of the puzzle which will hopefully lead to a better protection of nature and therewith also a safer future for humanity.

I want to conclude with a quotation by Gretchen Daily who suggests the potential role of ecosystem services within sustainability and conservation science: "Yet, ascribing values to ecosystem goods and services is not an end in itself, but rather one small step in the much larger and dynamic arena of political decision making" (2009, p. 23).

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Appendix

Appendix A: Data Input Overview for Carbon Model plus Uncertainty Ranking

#	Input Name	Content	File_type	Source	Methodology / Explanation	Comment	Degree of Certainty
1	Current Land Use / Land Cover	A GDAL-supported raster representing the land-cover of the current scenario	Raster (.adf-file)	University Lisbon	Raster File map. Converted with ArcGIS from a polygon shapefile.	A detailed map of the study area; created by the ecology & conservation team at UL.	High
2	Future Land Use / Land Cover	A GDAL supported raster representing the land-cover of the future scenario	Raster (.adf-file)	University Lisbon; own illustration; Rui Alvez	This is the future scenario map. The maps have been created in collaboration with UL and Rui Alvez, forest manager of Companhia das Lezírias.	.	High
3	Carbon Pools	A table that maps the land-cover IDs to carbon pools. Above-, belowground, Soil and dead matter carbon	Table (.csv-file)	University Lisbon; Literature	The values are taken from my colleagues at University Lisbon or gathered from literature.	LULC: Wetland, permanent culture, water and humanized have null values.	
3.1	C_above	Amount of carbon stored in aboveground biomass	Numeric Value	Faias et al. 2007, Correia et al. 2007, Castro & freitas 2008	LULC: No values for Riparian and annual crops. The conversion factor used to calculate t C/ha was 0.5 for tree dominated areas and 0.47 for grass-dominated areas (based on IPCC recommendation).	These papers provided Portugal-specific input data.	Medium
3.2	C_below	Amount of carbon stored in belowground biomass	Numeric Value	Faias et al. 2007, Correia et al. 2007, Ruiz-Peinado 2012, Martinez et al 1998, Boutton et al 2009	LULC: No values for Riparian and annual crops.	These papers provided Portugal-specific input data.	Medium
3.3	C_soil	Amount of carbon stored in soil	Numeric Value	IPCC 2006; Freyerova, 2014	According to the TESSA results, I calculated the average distribution of soil type for each LULC-type. Using the Tessa values for Regosol and Solonchak, plus the Freyerova, values for Podzol I calculated the average carbon content for each LULC-type.	There are three main types of soil in the Montado, Podzol, Regosols and Solonchak. The values for podzols are taken from Freyerova, 2014 who conducted their study in the Czech Republic, therefore certainty is low.	Low
3.4	C_dead	Amount of carbon stored in dead organic matter	Numeric Value	Faias et al. 2007; Gasparini et al. 2015	Transferring the TESSA values to the InVEST .csv file.		Medium
4	Current Harvest Rate Map	An OGR-supported shapefile containing information about harvested wood products for the current scenario	Shapefile (.shp)	Based on Charneca shapefile from University Lisbon.	The attribute table of the shapefile contains the harvest detail values. See below.		

4.1	Start Date	The first year the carbon removed from a forest will be accounted for in the Harvest Wood Product pool.	Numeric Value	Own assumption.		I numbered the parcels in a 9 year succession, starting 2004 to depict the harvest characteristics of cork	Low
4.2	Freq_cur	The frequency, in years, with which the Cut_cur amount is harvested.	Numeric Value	Bugalho et al, 2011; Personal communication with M. Santos-Reis; Companhia das Lezírias homepage.			High
4.3	BCEF_cur	An expansion factor that translates the mass of harvested wood into volume of harvested wood (Biomass Conversion Expansion Factor).	Numeric Value	InVEST UserGuide Suggestion.		The source recommended by InVEST is IPCC Report, chapter 4: Forest Land, Table 4.5. The table, however, does not contain values for cork oaks which is why I used the generic value suggested by InVEST	Medium
4.4	C_den_cur	The carbon density in the harvested wood.	Numeric Value	Gil L, Pereira C, 2007. A fórmula da cortiça. Tecnologia e Vida, November.	Shows the carbon content of the harvested good. For cork the value is 0.573709 according to the source.		High
4.5	Decay_cur	The half-life of wood products harvested, measured in years.	Numeric Value	Diaz et al, 2014	Half-Life of wood product; calculation based on Diaz et al 2014; value: 3.6; 70% of cork production goes into stoppers. 20% (personal estimation for other products) 10% for floor insulation	It is difficult to calculate this as cork decays over a long time if stored in a landfill. However, many cork stoppers are incinerated relatively fast after their use and therefore C is immediately released. The treatment also greatly depends on the country of consumption.	Low
4.6	Cut_cur	The amount of carbon typically removed from a parcel during a harvest period.	Numeric Value	Costa, 2007	The paper calculated the average production value of cork for companhia, which is 186 kg/ha.	Costa, 2007 conducted her research specifically for my study area (Companhia das Lezírias). All values have benn converted to Mg/ha.	High
5	Future Harvest Rate Map	An OGR-supported shapefile containing information about harvested wood products for the future scenario	Shapefile (.shp)	Based on the three future scenarios created for the study area	The attribute table of the shapefile contains the harvest detail values. See below.		
5.1	Freq_fut	The frequency, in years, with which the Cut_fut amount is harvested.	Numeric Value	Bugalho et al, 2011; Personal communication with M. Santos-Reis; Companhia das Lezírias homepage.	No changes to the current values.		High
5.2	BCEF_fut	An expansion factor that translates the mass of harvested wood into volume of harvested wood (Biomass Conversion Expansion Factor).	Numeric Value	InVEST UserGuide Suggestion.	No changes to the current values.	The source recommended by InVEST is IPCC Report, chapter 4: Forest Land, Table 4.5. The table, however, does not contain values for cork oaks which is why I used the generic value suggested by InVEST	Medium
5.3	C_den_fut	The carbon density in the harvested wood.	Numeric Value	Gil L, Pereira C, 2007. A fórmula da cortiça. Tecnologia e Vida, November.	No changes to the current values. Shows the carbon content of the harvested good. For cork the value is 0.573709 according to the source.		High

5.4	Decay_fut	The half-life of wood products harvested, measured in years.	Numeric Value	Diaz et al, 2014	No changes to the current values. Half-Life of wood product; calculation based on Diaz et al 2014; value: 3.6; 70% of cork production goes into stoppers. 20% (personal estimation for other products) 10% for floor insulation	It is difficult to calculate this as cork decays over a long time if stored in a landfill. However, many cork stoppers are incinerated relatively fast after their use and therefore C is immediately released. The treatment also greatly depends on the country of consumption.	Low
5.5	Cut_fut	The amount of carbon typically removed from a parcel during a harvest period.	Numeric Value	Costa, 2007	No changes to the current values. The paper calculated the average production value of cork for companhia, which is 186 kg/ha.	Costa, 2007 conducted her research specifically for my study area (Companhia das Lezírias). All values have benn converted to Mg/ha.	High
6	Value of Carbon	Price of Carbon per Metric Ton	Numeric Value	InVEST UserGuide.		I followed the recommended value of USD 66.00 per ton of C according to Tol, 200, from the userguide.	Medium
7	Market Discount in Price of Carbon	Market discount rate as integer percent.	Numeric Value	InVEST UserGuide.	The default value in the interface is 7% per year, which is one of the market discount rates recommended by the U.S. government for cost-benefit evaluation of environmental projects.	The value depends on country and landscape but I wasn't able to determine the correct value for a portuguese Montado. Therefore I use the recommended value of 7%	Medium
8	Annual Rate of Change in Price of Carbon	The integer percent increase in the price of carbon per year.	Numeric Value	InVEST UserGuide.	The default value in the interface is 0%. It is difficult to determine the future value of carbon sequestration, because in some scenarios future sequestration will be worthless if we already passed certain thresholds. In other scenarios the value of C sequestration might even increase in the future.	Due to the uncertain character of future carbon prices I will use '0 %' as the annual rate of change.	Medium

Appendix B: Data Input Overview for Timber Model plus Uncertainty Ranking

#	Input Name	Content	File_type	Source	Methodology / Explanation	Comment	Degree of Certainty
1	Managed Area Map	An OGR-supported vector file projected in meters.	Shapefile (.shp)	University Lisbon	Raster File map. Converted with ArcGIS from a polygon shapefile.	A detailed map of the study area; created by the ecology & conservation team at UL.	High
2	Plantation Production Table	A data table of information about the timber parcels on the landscape.	Table (.dbf-file)	Based on the attribute table of the managed area map; for details, see below.			
2.1	Perc_harv	The proportion of the timber parcel area that is harvested each harvest period; units are integer percent.	Numeric value	Logical assumption.	Each parcel is considered to be harvested 100% every 9 years	The values will remain the same, and therefore correct; the spatial distribution in terms of which parcel gets harvested when will change. But this doesn't affect this model.	High
2.2	Harv_mass	The mass of wood harvested per hectare (in metric tons (Mg) ha-1) in each harvest period.	Numeric value	Augusta Costa, 2008, Dissertation	Costa, 2008, calculated the average amount of cork harvest per year per hectare	Numbers should be sound, because they're specifically for Companhia. But they do differ for Rui's numbers from the one document, which doesn't make sense.	High
2.3	Freq_harv	The frequency of harvest periods, in years, for each parcel.	Numeric value	Management practice of Companhia das Lezírias, contact Rui Alvez.	Harvest cycles are every 9 years	Number adopted directly from Companhia das Lezírias.	High
2.4	Price	The marketplace value of the wood harvested from the parcel	Numeric value	Relatório Final Análise do sector e da fileira da cortiça em Portugal, 2012	Number from the annual report 2010; the value is mean price of cork from 2000 - 2010.		High
2.5	Maint_cost	The annualized cost ha-1 of maintaining the timber parcel, if any	Numeric value (€ / ha)	Companhia das Lezírias, Rui Alvez	Taken from their documentation and personal communication.	Although they document all their expenses, giving a per hectare value of *maintenance* costs is very tricky. Many of the maintenance acitivites are conducted for several LULC at a time and can't be traced back to only Montado.	Low
2.6	harv_cost	The cost (ha-1) incurred when harvesting Harv_mass.	Numeric value (€ / ha)	Companhia das Lezírias, Rui Alvez	Taken from their documentation and personal communication.	Number are presented in €/arroba and have beeny calculated back to €/ha.	High

2.7	T	The number of years from yr_cur or yr_fut that parcel harvests will be valued.	Numeric Value	Logical assumption.	If the harvest is expected to be an immediate one time clear cut T = 1.	Cork harvest is special as the trees are not felled but remain. So setting the T-value to 1 indicates a clear cut. Setting it higher is not possible because the T-value is geared towards the harvest frequency and percentage of harvest. Setting the T-value to 1, however, seems to indicate only 2 periods of harvest which does not reflect reality.	Medium
2.8	Immed_harv	This attribute answers whether a harvest occurs immediately – whether a harvest occurs in yr_cur, or whether the user is evaluating a forest parcel associated with a future LULC scenario occurring in yr_fut.	Numeric Value	Logical assumption.		I assumed an immediate harvest becaue the area of interest is already in operation and harvest happens every year	High
2.9	BCEF	An expansion factor that translates the mass of harvested wood into volume of harvested wood.	Numeric Value	InVEST UserGuide Suggestion.		The source recommended by InVEST is IPCC Report, chapter 4: Forest Land, Table 4.5. The table, however, does not contain values for cork oaks which is why I used the generic value suggested by InVEST	Medium
3	Market Discount Rate	The market discount rate reflects society's preference for immediate benefits over future.	Numeric Value	InVEST UserGuide Suggestion.		The value depends on country and landscape but I wasn't able to determine the correct value for a portuguese Montado. Therefore I use the recommended value of 7%	Medium

Appendix C: Introducing the Three InVEST Models in Detail

Visitation: Recreation and Tourism – Model

By employing the recreation model I want to address the cultural services provided by the study area. Since empirical data for recreational visitation is often hard to obtain for larger areas, the model uses geotagged pictures[17] from the website flickr[18]. The model uses "the average annual number of photo-user-days from 2005-2012" (Sharp et al., 2014, p. 169) for the calculation. In order to relate the geotagged photographs to the LULC of the targeted area, InVEST uses "a simple linear regression [which] relates average photo-user-days per cell to coverages of attributes across grid cells within the study region" (Sharp et al., 2014, p. 169). The inserted maps are overlaid with a hexagonal grid with user-adjustable cell sizes. Further, the model allows different future scenarios and predicts, based on the regression analysis from the base area, the changes in visitation for each scenario.

Data needs include shapefiles of the study area and the respective scenarios. The model is divided into two stages. The first stage is the initialization tool which runs the initial regression analysis. The second stage applies the results of the first stage to the different user-defined scenarios. The main output from this model is a gridded map of the study area which depicts the photo-user-days per year and the respective predictor variable for each cell.

Carbon Storage and Sequestration: Climate Regulation –Model

The carbon model addresses a landscape's ability to store and sequester carbon and calculates the monetary value of this service. The model uses a gridded map of the study area with a specific land-use assigned to each grid cell. Terrestrial carbon storage "largely depends on the sizes of four carbon 'pools': aboveground biomass, belowground biomass, soil, and dead organic matter" (Sharp et al., 2014, p. 70). For each land-use type the model requires information about the carbon content for at least one of the four carbon pools. Additionally, InVEST allows a fifth, optional carbon pool which applies to parcels which are Harvested Wood Products (for this case the harvested wood products are exclusively cork), such as firewood, charcoal or timber. Using the gridded LULC map plus the information from the carbon pools, "this model estimates: the net amount of carbon stored in a land parcel over time; the total biomass removed from a harvested area of the parcel, and the market and social values of the carbon sequestered

[17] Pictures with geographical identification metadata
[18] Flickr is an image and video hosting website, see https://www.flickr.com/

in remaining stock" (Sharp et al., 2014, p. 71). These results are made available as raster maps with respective values for each grid cell.

The carbon model allows future land-use scenarios which allows me to employ the three scenarios presented in Chapter 4.1.1. Further, I will include Cork Products with adjusted values for each of the three future LULC scenarios.

Managed Timber Production – Model

To cover the field of Provisioning ES I use the timber model. The timber model "analyzes the amount and volume of legally harvested timber from natural forests and managed plantations based on harvest level and cycle" (Sharp et al., 2014, p. 223). Originally, the model estimates the amount of roundwood harvested. However, the data input is user-dependent and can be adjusted to fit several purposes allowing me to modify it with regards to cork harvest. By including economic data about the market value of the harvested good the model can predict the anticipated value for each harvest parcel.

The timber model runs on a vector map of the study area. For each parcel that is subject to harvesting the user provides a dataset containing relevant harvest information. For the financial valuation the model uses a price for the harvested good and a market discount rate to calculate the net present values (NPV). The output of the timber model is a shapefile containing information on the net present economic value of timber production, the total biomass removed from each parcel and total volume of wood – or, in this case, cork – removed from each parcel.

In contrast to the carbon model, the timber model does not work with LULC classes to map the future scenarios. In order to account for changes among each scenarios I adjusted variables for the harvest calculations. While *price*, *immediate harvest*, the *BCEF-factor*, the *harvest frequency* and the *harvest ratio* remain stable for each scenario, *maintenance costs, harvest costs, and harvest mass* alter in the respective scenarios. Table 2 shows the changes in the three variables for each scenario and compares them to the base.

	Base	Urbanization (converted areas)	Cattle Intensification	Forest Improvement
Harvest Mass (kg / ha)	186	45	158	260
Maintenance Costs (€ / ha)	30	10	30	30
Harvest Cost (€ / ha)	44.64	10.8	37.94	62.4

Table: Changes in harvest values for each scenario. The table shows the changes for the total harvest mass, maintenance costs and harvests costs per hectare for each of the scenarios. Red fields show reducing values, yellow stable and green increasing values. *Urbanization* shows the values only for the areas that have been converted to residential land and therefore display reduced harvest activities. The remaining parcels have unchanged values. *Cattle Intensification* shows a reduction in harvest mass (hence harvest cost, too) while *Forest Improvement* shows an increase in both. Maintenance costs for these scenarios remain steady.

Another aspect which needs to be considered for the timber model is the total amount of harvestable area. The base scenario supports 5,814 ha of harvestable Montado. Both, *Urbanization* and C*attle Intensification* show lower numbers of harvestable area while *Forest Improvement* presents an increase of Montado area by almost 900 hectare.

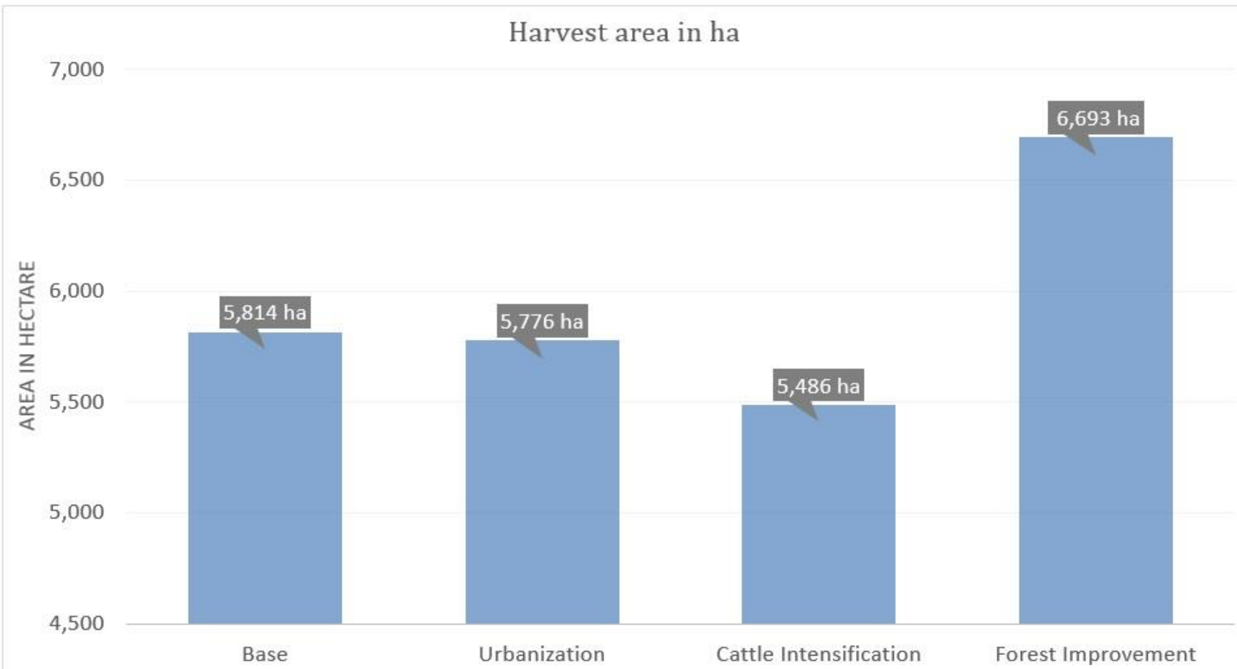

Figure Harvest area in hectare for base and future scenarios. *Urbanization* shows only little changes in area, because only the two converted parcels for housing underlie changes in harvest rates. *Cattle Intensification* shows a noticeable decline in harvested area while *Forest Improvement* expresses the highest margin in contrast to the base scenario.

Appendix D: The development of Conservation Frameworks from 1960 – 2010.

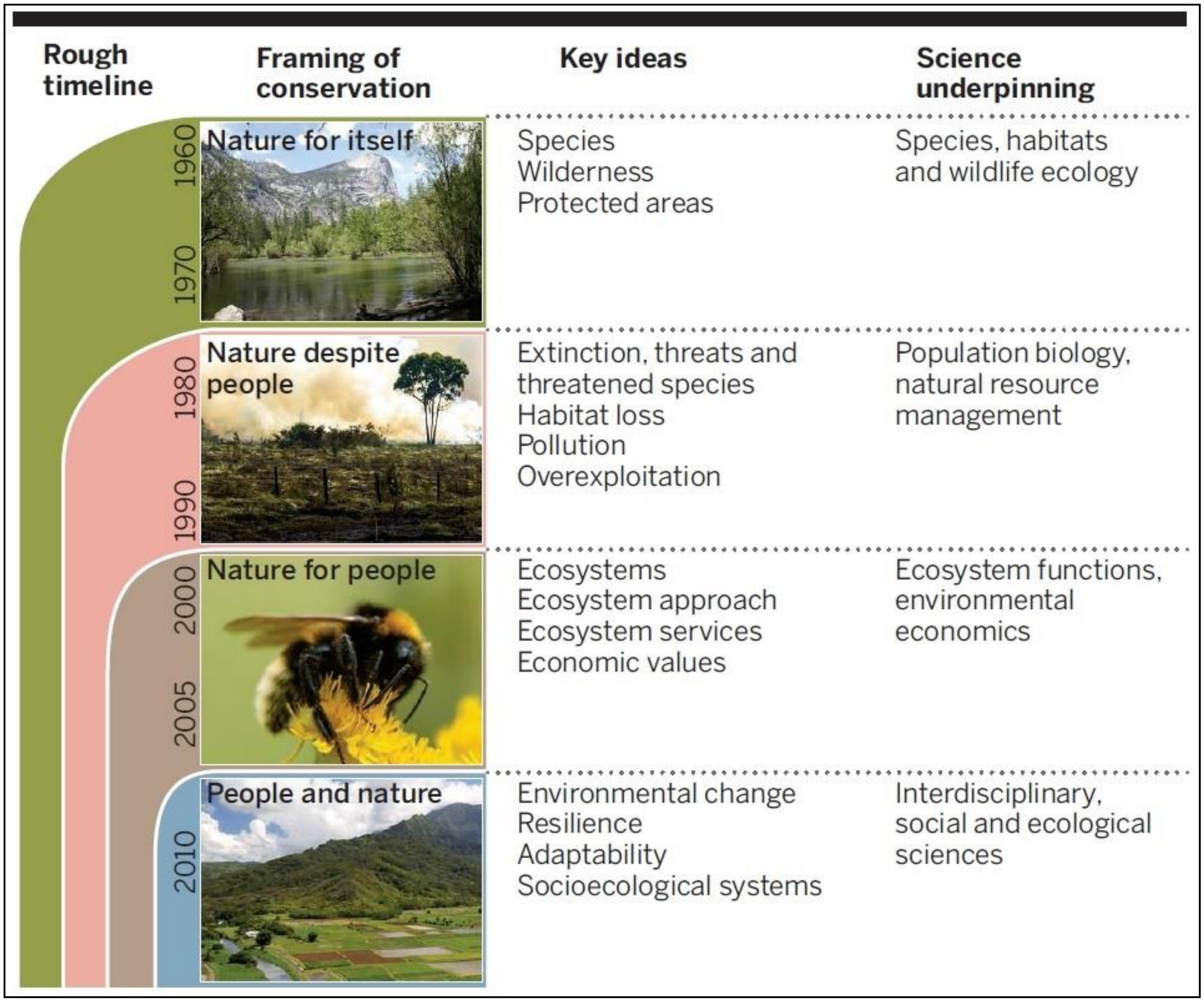

Figure: The development of Conservation Frameworks from 1960 – 2010. The timeline shows the conservation frameworks which have developed from 1960 to 2010, including their key ideas and scientific underpinning. None of the frameworks have been ruled out completely with the introduction of new frameworks, leading to the co-existence of multiple frameworks today. Source: Mace (2014).Although organizations and structures within conservation science have largely remained the same over the past 50 years, the purpose and framing of conservation have shifted (Mace, 2014). The figure displays the development of conservation science frameworks since the 1960's. Starting off with a *Nature for Itself* approach the view shifted towards a more human-centered approach in the 2000's framed as *Nature for people.* ES are listed as a key idea for this framework. This development happened over a rather short period of time and the appearance of one framework did not eclipse the other, leaving behind a pluralism of views underlying conservation (Mace, 2014).

Appendix E: Development of Cork Prizes, Production and Area

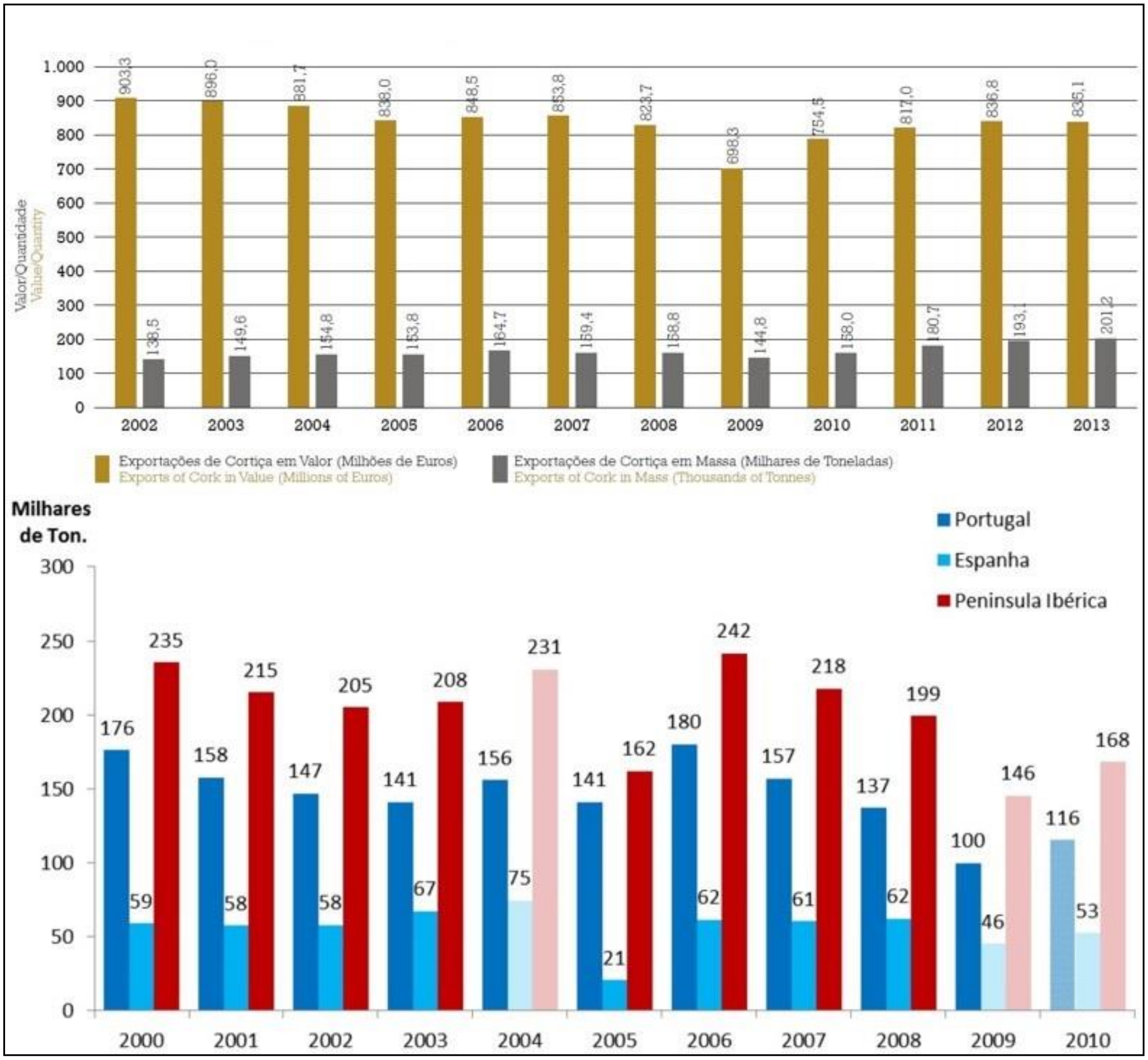

Figure: Evolution of Cork Exports 2002-2013 and Development of cork production on the Iberian Peninsula 2000-2010. The upper maps shows Portugal's total cork export between 2002 and 2013 in thousand tons (grey bars) and the value of the export in millions of Euro (ocher bars). The total exported mass remains relatively stable with a slight negative trend towards 2013 and a dip in 2009. The value of the export are relatively stable, too, but show a slight increase over the period. The bottom map depicts total cork production in the Iberian Peninsula (red), Portugal (dark blue) and Spain (light blue) in thousand tons. The total produced mass fluctuates noticeably between 2000 and 2010 with a minimum value in 2009. The overall trend is negative for all localities, but with 2010 showing a recovery from 2009. Sources: upper chart from (APCOR, 2014), bottom chart from (Autoridade da Concorrência, 2012).

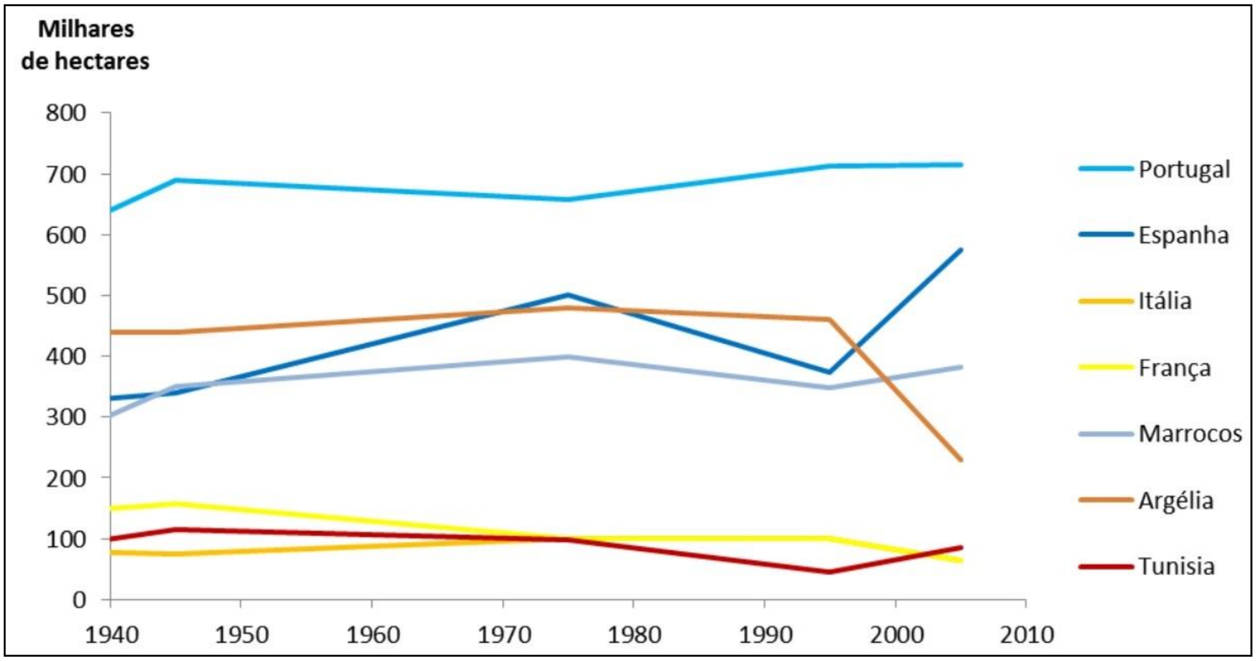

Figure: Development of total cork oak area from 1940-2005. The figure shows the development of total cork area for seven cork producing countries in the Mediterranean. While Algeria (brown) and France (yellow) show declining cork oak areas, the overall trend is stable. Portugal (light blue) supports the largest area of cork oak and depicts a steady trend around 700 million hectares with a slight increase towards the 1990's and 2000's. Source: (Autoridade da Concorrência, 2012).

Despite the internal and external pressures the total Montado area has been comparatively stable over the past decades (M. Santos-Reis, M. Bugalho, personal communication, February 11, 2015;). One reason for this stability is the legal regulation that prohibits the felling of cork oaks in Portugal. However, as of late researchers and land owners recognize increasing cork oak mortality and degradation of stand quality (M. Santos-Reis, M. Bugalho, personal communication, February 11, 2015; Costa, Pereira, & Madeira, 2010). Some research assume a suite of factors causing the premature oak death, including harmful fungi, the use of heavy farming machinery and the growing impact of climate change in the form of droughts

(M. Bugalho, personal communication, February 11, 2015).

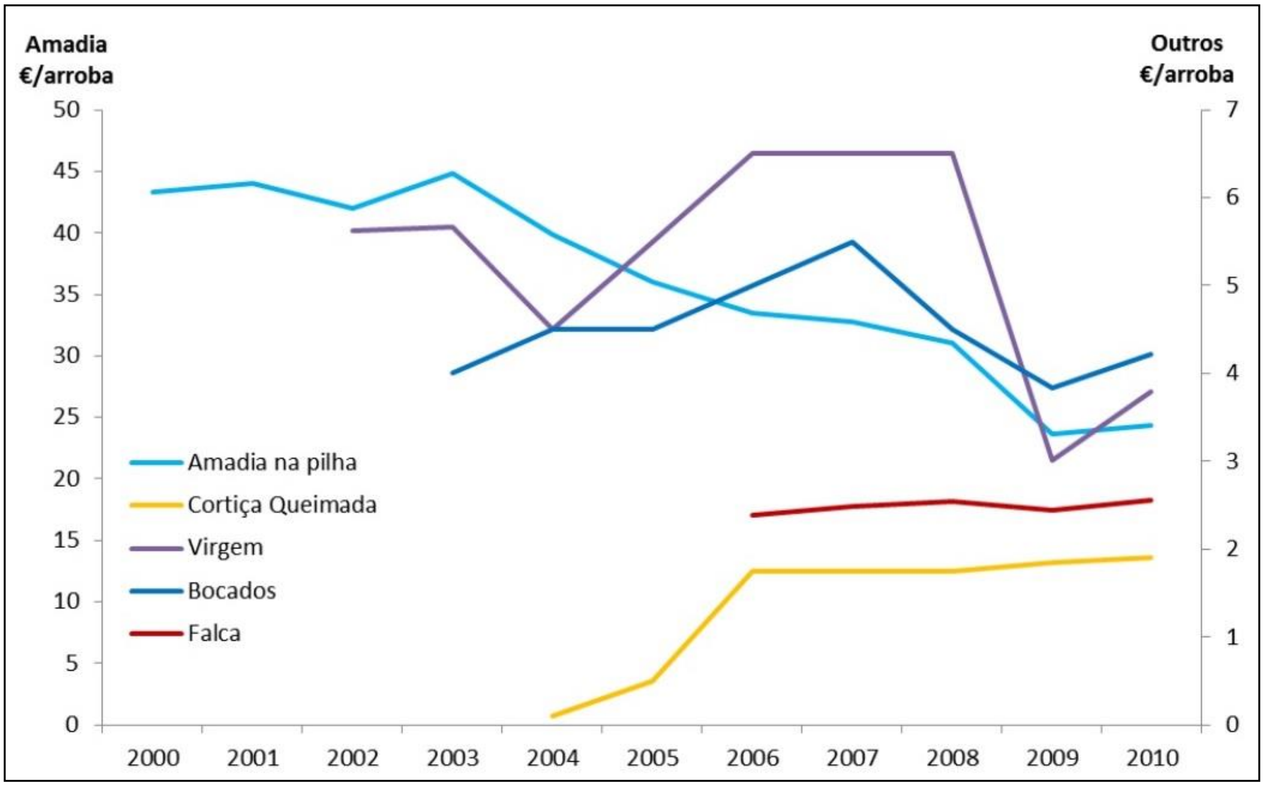

Figure Cork price development 2000 – 2010. The figure shows the price development of five different types of cork over the years 2000 to 2010. Amadia (light blue) is the most valuable and most harvested type of cork and therefore accounting for the majority of the revenue. The other types include for example virgin harvest (purple) and fractions (dark blue). The trend for amadia cork is strictly negative since 2003 with a recovery in 2010. The total loss in value from 2000 to 2010 is around 20 €.The overall trend for cork price is negative. Source: (Autoridade da Concorrência, 2012).

Appendix F: Recreation Model Results

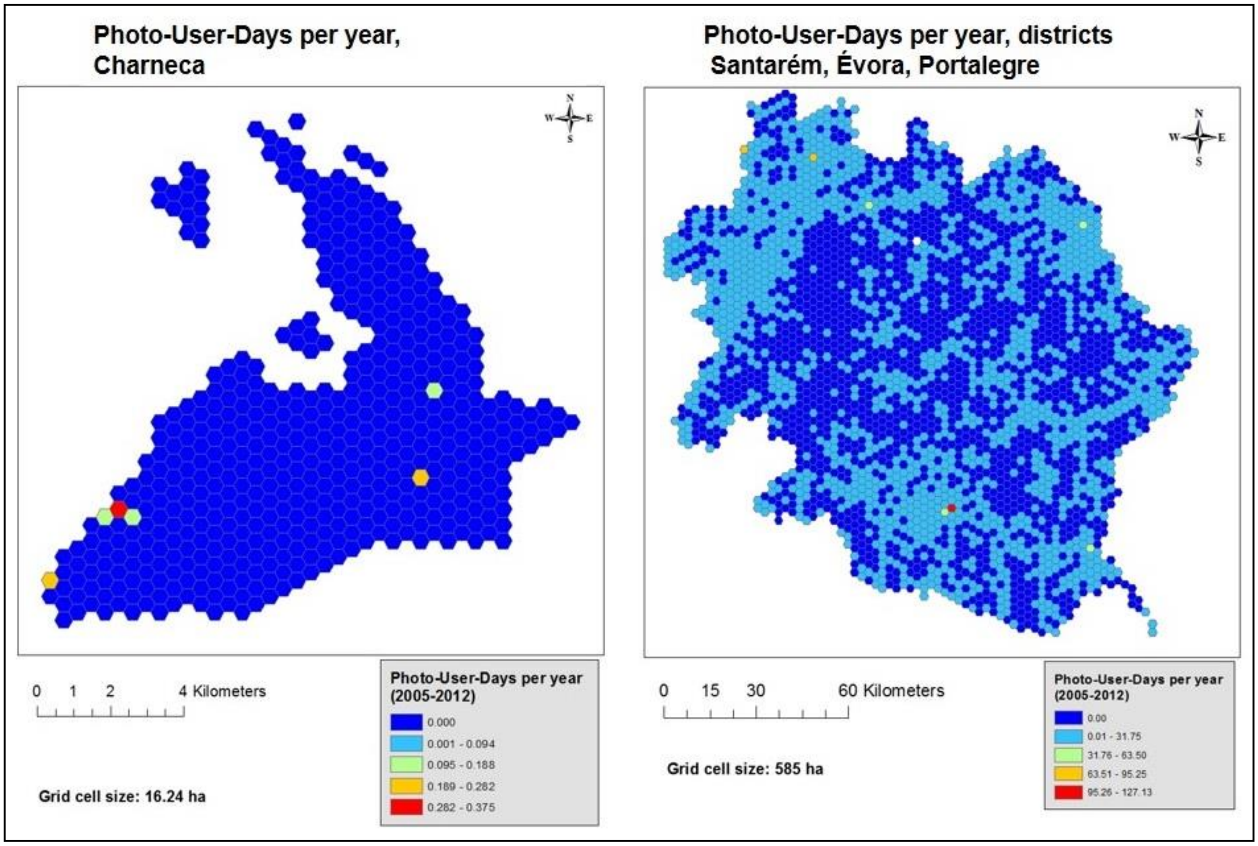

Figure: Photo-User-Days per year for Charneca and comparative site from 2005-2012. Photo-User-Days per year express the "total annual days that a user took at least one photograph within each cell" (Sharp et al., 2014, p. 169) averaged over the period of 2005 to 2012. The left map represents the study area Charneca and shows very low value for annual photo-user-days. The right map is a comparative site consisting of three Portuguese districts: Santarém, Portalegre, and Évora. This maps was used to check if the low values for Charneca could be traced back to the size of the area. The comparative site shows very low values, too, except for a few hotspots (e.g. the city of Évora, or Fátima).