FIREURISK - DEVELOPING A HOLISTIC, RISK-WISE STRATEGY FOR EUROPEAN WILDFIRE MANAGEMENT

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Executive Summary

The assessment of ecosystem services value and the quantification of wildfire impacts on them is an increasingly important demand of forest and land managers as well as of fire managers, due to it is a meaningful component of the vulnerability section of the risk scheme. Ecosystem services are part of complex and integral systems in which everything is correlated. Therefore, the quantification of wildfire impacts requires an integrated approach by way of a combination of ecological, economic, and social considerations.

The aim of this paper is to describe and detailed explain a methodological framework for assessing economic fire impacts on both tangible and intangible ecosystem services. The University of Córdoba, as a partner of FirERUrisk project, propose SEVEIF model (System for the Economic Evaluation of Forest Fires) as a methodology to calculate potential losses on ecosystem services affected by wildfires, and develop the implementation of it in the five designed Pilot Sites: PS1 Northern Europe, PS2 Central-Eastern Europe, PS3 Mediterranean (Portugal), PS4 Mediterranean (Spain) and PS5 Mediterranean (Greece). In this paper, the results achieved in PS4 Mediterranean (Spain) are shown as an example of the methodology application. The assessment in the rest of the pilot sites is in process.

SEVEIF model is a pioneering methodology that brings the contributions of several different previous approaches and researches. There is no other model as complete as it. Currently, SEVEIF model includes the assessment of the following ecosystem services, grouped into two categories according to type:

- provisioning services: timber and non-timber products
- regulating, support and cultural services: carbon sequestration and storage, erosion control, flagship or endangered fauna species, landscape, leisure, and existence services

Apart from SEVEIF model, regulating, support and cultural services are seldom included in economic assessment of natural resources, even though these kind of resources constitute a large proportion of the total ecosystem value.

Furthermore, SEVEIF model extends the economic assessment theory to economic vulnerability using time restoration or vegetation resilience (years needed for restoring the original resources values). SEVEIF model incorporates the concept of net-value change, considering the pre-fire value of each resource and depreciation ratio based on fire behaviour. Firstly, the economic assessment required the individualised study of the pre-fire value of each resource using its specific input data and mathematical formulation. Subsequently, fire behaviour was simulated in order to estimate the potential flame length, which is easier to identify in field sampling than fire intensity. Fire behaviour was then classified into seven categories or Fire Intensity Levels (FILs). The depreciation ratio for each FIL is expressed as a percentage value to simplify the methodology and field inventories. Finally, the net value change of each resource (value loss or value gain) is calculated as the product between ecosystem services value and FIL. The sum of all potential impacts on environmental services is presented as the Potential Fire Impacts in each Pilot Site.

The SEVEIF model methodology has been tested in Southern Spain (Sierra Morena demonstration area), therefore, it is assumed to be fully applicable to other Mediterranean regions of Europe. Although replicability in other European ecosystems has not been proved yet, it could be applied through the customization of the variables, since the model allows the end user to modify the value that not fit with the studied territory.

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Visual-SEVEIF and AppERIIF are tools to assist in the implementation of the SEVEIF model. They are downloaded for free (www.labif.es). These ecosystem service assessment support tools can be useful in different decision-making approaches as prevention, suppression and post-fire, predominantly regarding fuel treatment prioritisation, cost-efficient management, and budget allocation. A part from Visual-SEVEIF and AppERIIF, there are no other similar tools in the scientific or management community for estimating the potential fire impacts, therefore its utilization is so enriching and facilitating the process of assessment potential losses on ecosystem services due to wildfires.

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List of Acronyms

Table 1: List of Acronyms

List of Acronyms	
SEVEIF	System for the Economic Evaluation of Forest Fires
FIL	Fire Intensity Level
NVC	Net Value Change
GIS	Geographic Information System
IUCN	International Union for Conservation of Nature

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1 Introduction

FirEUrisk project appraise the location, intensity, frequency and probability of fires. It evaluates fire danger and the exposure and vulnerability to fires in different areas, and the effects of fires on people, property, ecosystems and the environment. FirEUrisk project looks into risk from different perspective: assessment, reduction and adaptation. This deliverable (D1.6) is part of the assessment step of FirEUrisk, in particular in Task 1.2. This task aims to valuate exposure and vulnerability and it is integrated in the WP1, which main goal is to assess Fire risk to improve prevention.

Although fire has played an essential role in shaping the Mediterranean landscape (Naveh, 1994), severe larges fires have become a threat to natural resources (Pausas and Fernández-Muñoz, 2012; Rogers et al., 2020). Large fires cause not only ecological damage, but also have both social and economic impacts (Martinho, 2019). Wildfires are disturbances that affect natural resources, to a greater or lesser extent, including both direct fire impacts (incidence of flame, heat, and smoke) and indirect impacts (i.e. habitats changes), mainly derived from the loss of soil and vegetation cover. The occurrence of fire promotes the temporary reduction or disappearance of vegetation cover (Whelan, 1995) and the net value change of natural resources (Rodríguez y Silva and González-Cabán, 2010). The net value change is the economic value change experienced by the natural resources affected by wildfires, comparing a situation pre-fire and post-fire. The net value change is conditioned by fire intensity (Finney, 2005) and vegetation resilience (Chuvieco et al., 2014). Wildfires usually have a negative impact on natural resources, consequently degrading them and depreciating their value. However, some low severity fires could be beneficial for certain resources, consequently increasing their value (Milne et al., 2014).

Ecosystems provide natural resources in all their forms (products or services). The Food and Agriculture Organization of the United Nations (FAO, 2023) defines ecosystem services as the multitude of benefits that nature provides to society, making human life possible and offering recreational, cultural, and spiritual benefits. FAO distinguishes between four types of ecosystem services:

- Provisioning services. These are the tangible assets that people obtain from ecosystems and that are traded in markets. These include, for example, the supply of food, water, fibres, wood and fuels.
- Regulating services. These are the benefits obtained from the regulation of ecosystem processes. They are mostly invisible and, therefore, are often taken for granted. If these services are damaged, the losses could be significant and difficult to recover. Regulation of air quality and soil fertility, flood and disease control, and crop pollination can be included as regulating services.
- Support services. These are necessary to produce all other ecosystem services, providing spaces in which plants and animals live, allowing species diversity and the maintenance of genetic diversity.
- Cultural services. These are the intangible benefits that people obtain from ecosystems and are among the most important values that people associate with nature. These services include aesthetic inspiration, cultural identity, sense of belonging, and spiritual experience related to the natural environment. This type of services typically also includes both tourism and recreational activities.

The assessment of the impacts of wildfires on ecosystem services requires an integrated approach by way of a combination of ecological, economic, and social tools (Castellano et al., 2000; Farber et al., 2002; Rodríguez and Silva et al., 2008). The objective of economic assessment is the monetary quantification (in terms of euros per hectare) of

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the impact that fire has on natural resources, based on the net value change of the resources (NVC). The economic assessment of the wildfire impacts is considered to be a complex analysis for several reasons. Firstly, in the territories affected by forest fires, there are several types of economic activities that generally exist simultaneously: agriculture, forestry, livestock, hunting, etc., in addition to many ecosystem services. This requires an adequate and exhaustive identification of the natural resources affected by fire. Additionally, obtaining valuation algorithms for natural resources, especially those which are intangible, as well as depreciation matrices for the NVC, gives rise to difficulties and requires prior study and research. Different economic models are considered in order to achieve a comprehensive economic assessment of tangible assets, environmental services, and landscape goods. Despite the complexity of allocating monetary value to nature, it is a fundamental need in the decision-making process. This need is justified mainly for the following reasons:

- The need for sustainable use of natural resources. Natural resources in the form of products are limited, meanwhile, they are essential for life and indispensable for society in the form of services. There is significant social concern regarding the depletion of natural resources and a growing awareness of the efficient use of natural resources to ensure their sustainability.
- The deterioration of ecosystem services due to wildfires implies a loss in terms of quality of life. The economic quantification of the fire impacts would facilitate knowledge regarding the potential damages and enable the prioritisation of the most valued areas.
- The consequences of the relationship between economic losses, vulnerability, and risk. The economic losses derived from fire occurrence are an essential component of the Wildfire Risk Assessment, understood as the integration of hazard, vulnerability, and exposure. The impact of wildfires on natural resources depends, to a large extent, on their vulnerability. The vulnerability of a natural resource refers to its capacity to resist and recover from the impact of fire, i.e., its predisposition to suffer ecological or economic losses. Therefore, the more vulnerable a resource is, the greater the losses will be, ultimately increasing the wildfire risk.
- The recommendation of cost-benefit analyses of wildfire suppression operations to make comparisons between suppression costs and the value of the saved ecosystem services. The social alarm caused by wildfire and its social and political relevance imply that a large amount of firefighting and economic resources are engaged in fire suppression. The allocation of resources can occasionally be considered disproportionate, and an adequate economic evaluation is required in order to justify this.
- The planning of effective forest management for the mitigation of socioeconomic impacts. The prioritisation of fuel treatments, mainly in of the case of budgetary restrictions, plays a keystone role in the reduction of fire consequences both for society and for future generations.

Forest and land managers demand tools to provide quantitative values to natural resources and economic fire impacts (Lipton et al., 1995). This methodology can therefore be a useful tool in terms of prevention and suppression approaches, predominantly in fuel treatment prioritisation, cost-efficient management, and budget allocation.

1.1 Purpose of the document

The main goal of this deliverable (D1.6) is to describe the methodology developed to assess socio-economic impact/damages of wildfires. Potential losses are essential products needed to be integrated in the conceptual scheme of Fire Risk, as a main component of the vulnerability.

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This deliverable (D1.6) is part of the assessment step of FirEUrisk (objective 2) as it generates potential losses derived from wildfires in order to be integrated in the assessment of European Fire Risk. In particular, D1.6 contributes to Task 1.2. This task aims to valuate exposure and vulnerability and it is integrated in the WP1, which main goal is to assess Fire risk to improve prevention. D1.6 is part of the set of eight deliverables of the WP1.
Besides, D1.6 is based on the outcome of T1.2.4, the deliverable D1.4, in particular for the methodology proposed on socio-economic assessment of damages and/or the main findings of D1.4 concerning the assessment of socio-economic impacts of fires.

1.2 Structure of the Document

This document is divided in four main sections:

- A theoretical description of the ecosystem services included in the methodological framework and their mathematical algorithms to assess economic fire impacts.
- A presentation of the free tools developed to calculate economic fire impacts on ecosystem services based on the net-value change.
- A brief description of the implementation of these tools to prevention, suppression, and post-fire approaches.
- A real application of potential fire impact assessment within the framework of FirEUrisk project. Free tools available in Forest Fire Laboratory (www.labif.es) have been implemented to PS4 Mediterranean (Spain).

2 Ecosystem services framework

According to FAO (2023), a resource refers to any material, product, service, or good that is used to satisfy human requirements and desires. Natural resources or ecosystem services are those obtained directly from nature. Depending on their perceptibility, i.e., whether they are physically perceived and can be seen, touched, or measured, ecosystem services can be classified into two groups:

- Provisioning services. Tangible resources with commercial value and are therefore subject to economic transactions. Thus, they are considered market goods.
- Regulating, support and cultural services. Intangible resources, environmental values with public good characteristics that are considered externalities and are usually assigned a use value (current use value + future use value) and a non-use value (option value + existence value). Society demands the assessment of this type of resources, despite lacking a market.

3 Methodological framework for fire impacts assessment

The fire impact assessment should not ignore ecosystem services and landscape goods, despite the difficulty regarding the assignment of monetary values (Hunt et al., 2005; Rodríguez y Silva et al., 2013). Different studies (Calkin et al., 2011; Parente and Pereira, 2016) have incorporated economic values of the natural resources in the risk assessment supporting decision-making. While some approaches (Chuvieco et al., 2010) promote categorical approaches to value

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economic impacts caused by a potential fire, other studies (Román et al., 2013; Alcasena et al., 2017) attempt to quantify the fire impacts in monetary terms.

The aim of the System for the Economic Evaluation of Forest Fires (SEVEIF model) is to identify a methodological framework to assess economic fire impacts on ecosystem services. SEVEIF model is a pioneering methodology that brings together the contributions of several different previous approaches and researches. There is no other model as complete as SEVEIF model. Firstly, the valuation of fire damages requires individualised study of the economic value (pre-fire) of each of the resources (tangible and intangible) present in the study area or fire. Subsequently, the net value change is identified by fire behaviour and ecosystem resilience (Rodríguez y Silva et al. 2012). While fire behaviour is undertaken using a "depreciation matrix" based on flame length intervals (Molina et al. 2011, Rodríguez y Silva et al. 2012), ecosystem resilience is identified according to dominant species (according to chapter 6 of deliverable D.1.4).

Conceptually, the economic assessment of fire impacts requires the following three main phases (Figure 1):

- Economic assessment of each resource based on the mathematical equations and their input variables.
- Depreciation ratio estimation for each natural resource according to fire behaviour.
- Integration of each resource value and depreciation to calculate the net value change or fire impact (value loss or value gain).

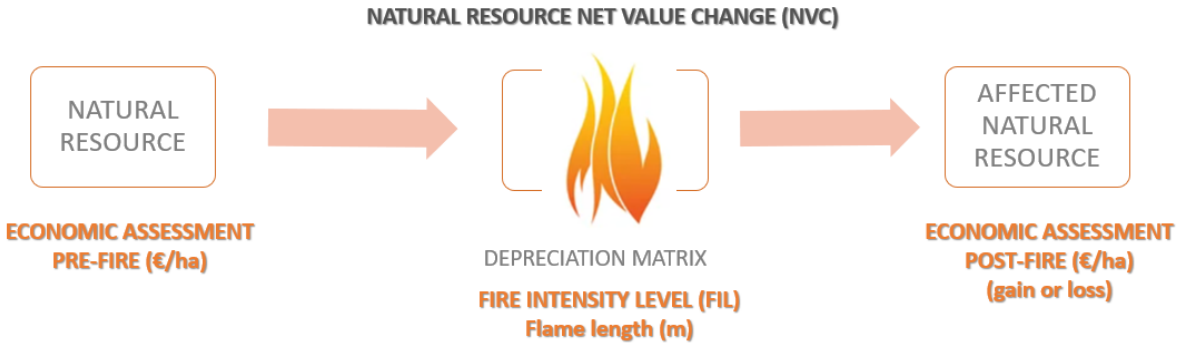


Figure 1: Methodological framework for fire impact assessment

The following steps were required in order to develop an operational economic assessment in accordance with these three main phases:

- Identification of the available resources and their spatial distribution in the burned area. This data is obtained from land use cartography and its reclassification into fuel models using standard classification (Rothermel, 1972) and/or FirEUrisk classification.
- Validation of the previous fuel model classification, through field inventories as well as enriching with local expertise (directly interview with forest or land managers).

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- Application of the SEVEIF model (mathematical algorithms) to identify the value of the resources before wildfire. AppERIIF or Visual-SEVEIF could be utilized as tools to assist in the implementation of the SEVEIF model for estimating the potential fire impacts. AppERIIF and Visual-SEVEIF, basis on requested inputs of the burned area, generate outputs (potential losses on ecosystem services affected by wildfires).
- Integration of the economic value of each resource and its spatial distribution using Geographic Information System (GIS) tools.
- Simulation (potential fire behaviour) or identification (real fire behaviour) of fire spread in the study area or fire. Fire simulators, such as BehavePlus, FlamMap and Visual-SEVEIF can be used to estimate fire intensity and flame length with real or majority meteorological conditions. Flame length is calculated from fire-line intensity (kW/h) using the Byram approach. Fire intensity and flame length are characterised in seven categories known as Fire Intensity Levels (FILs) (Table 2).

Table 2: FIL classification

FIL	Flame Length (m)	Fire Intensity (kW/m)
I	<1	< 260
II	1-2	260-1,172
III	2-3	1,172-2,830
IV	3-6	2,830-12,770
V	6-9	12,770-30,830
VI	9-12	30,830-57,620
VII	>12	> 57,620

- Identification of the depreciation ratio for each resource based on FILs. Data regarding large wildfires that occurred in Southern Spain have been used in order to estimate mean rates of depreciation based on fire behaviour.
- Allocation of the net value change of each resource based on the fire behaviour. Each resource (pre-fire economic value) is affected in a different way due to its depreciation matrix. The product between each resource value and its depreciation ratio results in an economic loss (€/ha). Fire impacts would be calculated as the sum of all resource losses.

Each phase of the operational assessment is described in detail below in order to give a better understanding of the methodology (Figure 1). The methodology could be applied in other territories as long as it is customized to the characteristics of them.

3.1 Economic algorithms for ecosystem service assessment

This section provides the algorithms integrated in SEVEIF model for the economic assessment of ecosystem services, separately for provisioning services and for regulating, support and cultural services. Several ways to assess the economic value of each ecosystem service are possible (willingness to pay, consider surplus, travel cost method, etc.). Further detailed references to this natural capital economic valuation approaches are made in chapter 7 of D1.4 of FirEUrisk project.

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As seen above, SEVEIF model application requires prior georeferencing of the ecosystem services to be valued. Likewise, local expertise is essential to identify the values of the inputs of the algorithms, customizing the process and adjusting the assessment as closely as possible to reality. The better the information provided, more accurate results or outputs can be generated.

The following subsections are a detailed description of how the calculation algorithm for Maximum Fire Impacts or Potential Losses is obtained for each ecosystem service and its mathematical expression.

3.1.1 Provisioning services

According to SEVEIF model, the tangible or provisioning services that may be included are:

- Timber products, such as timber, biomass, and firewood.
- Non-timber products, such as cork and fruits (chestnuts, pine nuts or acorns).
- Pasture.
- Hunting.

The assessments of provisioning services developed in SEVEIF-model are explained in this section. A reference to the identifier of each one is made in Table 3.

Table 3: Identifier of the Maximum Fire Impacts (€/ha) for provisioning services

Maximum Fire Impacts (€/ha)	
Identifier	**Ecosystem service**
L_{timber}	Timber
L_{fire}	Firewood
L_{fruit}	Non-timber products
L_{past}	Pasture
L_{hunt}	Hunting

3.1.1.1 Timber products

The timber products assessment requires the differentiation between stands without commercial harvesting or stands with commercial harvesting and an estimation of the stand age and rotation length. The algorithm is obtained from the integration of the National Fire Management Analysis System of United States (González-Cabán, 2000) and the Spanish methodology (Martínez, 2000). The integration of both methodologies allows us to use a mixed criterion in relation to the type of regeneration (natural or artificial). While the American methodology is based on the criterion of natural regeneration, the Spanish methodology considers artificial regeneration that varies based on stand condition and rotation length.

The fire impacts on timber products depends on its mature and immature condition (Table 4). The mathematical expressions depend on each methodology (B is American and E is Spanish) and stand condition (sapling-thicket, polewood and mature). Timber stock and prices are established using mean values according to dominant species and site quality. Finally, an integrated approach was computed by the relative importance of natural regeneration

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(American approach) and artificial regeneration (Spanish approach). For further details, please consult Rodriguez y Silva et al. (2012).

Fire occurrence also causes the loss of periodical profits, such as firewood and biomass harvesting. Firewood and biomass stocks and prices are established due to dominant species, stand density and rotation length, in a similar way to timber product. It is also interesting to note that firewood resource can only become profitable in some species (elevated price due to its heating power) and topographical condition (slope lower than 45% due to its possible mechanization).

3.1.1.2 Non-timber products

SEVEIF model includes different fruit resources, such as acorns, chestnuts, and pine nuts, as tangible non-timber products. The valuation of this type of natural resources starts with the determination of the maturity stage of the stand, the estimation of the annual income through production tables (Vázquez et al., 2001; Montero et al., 2004) and the identification of the market prices of the products. The formulation of non-timber resources (Table 4) depends on the annual production, the estimated price of the resource, the annual interest rate, and the number of years without resource harvesting. For further details, please consult Molina et al. (2011).

The cork harvesting is a periodical profit depending on the debarking intensity, weight of the cork and cork quality. Cork harvesting depends on the average annual cork yield (Montero et al., 1996), affected by the quantity of "bornizo" (cork without commercial use) and the area of poor cork removing (diseases, pests, or old age). Finally, cork quality and, therefore, cork price varies based on visual condition and cork thickness.

3.1.1.3 Pasture

Sustainable grazing capacity was estimated based on grasslands characterization and soil protection from erosion processes (only an amount of primary grass should be assigned for feeding). The valuation of pasture depends on substitute market products (hay, straw, barley, etc.), which are necessary to cover the protein and fibrous needs of livestock. Although the pasture improves its production in the following fire years, it could be negatively affected (loss of use) if livestock is not allowed until the regeneration of the rest of the ecosystem (Martínez, 2000). The assessment of pasture impacts is computed based on the annual income (which depends on the carrying capacity), the interest rate and the number of years using substitute market products (Table 4). For further details, please consult Molina et al. (2011).

3.1.1.4 Hunting

Hunting economic assessment is based on the different management units including both forest and agricultural ecosystems. The hunting value results as a sum of the updated and sustainable profit plus a value of the reproductive wildlife (Novak and White, 1989; Bozek and Young, 1994). The income obtained is established according to average capture fields for each species and vegetation type. It is important to note that these values may be underestimated in some game reserves, since they are based on recommended sustainable carrying capacity and not on real animals. Economic damage can be calculated by updating the profit over the years with the restricted hunting practices due to

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the lack of food and shelter plus the stock (Table 4). Restoration time in this resource is considered as the years of hunting restrictions necessary for natural regeneration of the ecosystem. Restoration time is directly related to the ecosystem composition and structure. For further details, please consult Zamora et al. (2010).

All the economic assessment algorithms of SEVEIF model for provisioning services are detailed below (Table 4).

Table 4: Mathematical algorithms for provisioning services

Ecosystem service	Mathematical algorithm	Resource condition	Source
Timber	$L_{timber} = (a*E*B)/(E+b*B)$	Mature and Immature	Rodríguez y Silva et al., 2012
	$E = C_0*p\ [i^e + g(i^e -1)] + A*(i^e - 1)$	Sapling, thicket	Martínez, 2000
	$E = (C_{0/z})*t\ [i^e + g(i^e -1)] + (C_0/z)*0.5*(i^e - 1)$	Polewood	Martínez, 2000
	$E = [P*V - P_1*V_1] + P*V\ [(i^y - 1)/(i^y)]$	Mature	Martínez, 2000
	$B = [(V*P*1.025^n)/1{,}04^n]*[1-(1.025/1.04)^e]*[1 + X*h*p]$	Sapling, polewood	González-Cabán, 2000
	$B = V*h*t[R*P + (1 - R)*P_1]$	Mature	González-Cabán, 2000
Firewood	$L_{fire} = P_x*R_x*[((1+i)^y - 1)/(i*(1+i)^y)]$	-	Martínez, 2000
Non-timber products	$L_{fruit} = P_x*R_x*[((1+i)^n - 1)/(i*(1+i)^n)]$	Mature	Martínez, 2000 Molina et al., 2011
Pasture	$L_{past} = P_x*R_x*[(1+i)^n - 1)/(i*(1+i)^n)]$	Silvopastoral system	Martínez, 2000 Molina et al., 2011
Hunting	$L_{hunt} = P_x*R_x*[(1+i)^n - 1)/(i*(1+i)^n)] + S$	Game reserves	Zamora et al., 2010

where "L" is the maximum fire impacts or losses (€/ha), "E" is the valuation according to natural regeneration or Spanish approach (€/ha), "B" is the valuation according to natural regeneration or National Fire Management Analysis System (€/ha), "a" takes the value of 1.7 or 2.6 based on the importance of timber resources in the burned area, "b" takes the value of 0.85 or 0.25 based on the same reasons, "C_0" is the costs of reforestation(€/ha), "i" is the compound annual interest rate and depends on species growth rate: fast growth (1.06), medium growth (1.04), slow growth (1.025) and very slow growth (1.015), "g" is the annual silvicultural cost factor and depends on species growth rate: fast growth (1.27), medium growth (1.1) slow growth (1.1) and very slow growth (0.93), "e" is the stand age, "P" is the timber or biomass price (€/m^3), "V" is the timber or biomass volume (m^3/ha), "y" is the time or years remaining in the harvesting rotation or senescence age (difference between rotation length and age), "V_1" is the volume of burned timber (m^3/ha), "P_1" is the price of affected timber with commercial use (€/m^3), "h" is the percentage of immature or mature timber in stand, "X" is the tree mortality coefficient depending on fire intensity (Rodríguez y Silva et al., 2012), "t" is the depreciation ratio based on flame length (0-1),"P_x" is the resource price or substitutive element price (€/kg), "R_x" is the annual ecosystem service production (depending on the ecosystem service: kg/year, stereo/year, etc.), "St" is the reproductive stock (€/ha) and "n" is the estimated number of years until vegetation recovery (years).

3.1.2 Regulating, support and cultural services

Although there are more regulating, support and cultural services that could be included, currently, SEVEIF model consider carbon storage, soil erosion, endangered species, landscape and leisure, and non-use services. The assessments of regulating, support and cultural services developed in SEVEIF-model are explained in this section. A reference to the identifier of each one is made in Table 5.

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Table 5: Identifier of the Maximum Fire Impacts (€/ha) for regulating, support and cultural services

Maximum Fire Impacts (€/ha)	
Identifier	**Ecosystem service**
L_{car}	Carbon storage
L_{eros}	Soil erosion
L_{endag}	Endangered or flagship species
L_{lands}	Landscape and recreational resources
$L_{non-use}$	Non-use or existence value

3.1.2.1 Carbon sequestration and storage

Wildfires not only cause an increase in carbon dioxide emissions, but also cause a decrease in the amount of carbon sequestration due to the elimination of tree and shrub cover (Cardoso de Mendoza et al., 2004). Carbon storage from each land use was georeferenced using GIS, including both forests and treeless territories. In forested areas, carbon sequestration is associated to stem, crown, and root strata. Stem storage is calculated from the timber stock, which corresponds to the data generally provided by forest inventories. The timber volume is transformed into dry biomass using the wood density. The crown expansion factors transform the biomass at stem level into total aboveground biomass (Figueroa and Redondo, 2007). The ratio of root biomass to aboveground biomass has been incorporated from the biomass study carried out by INIA-EGMASA (Aguado et al., 2007). The estimation of shrub and understory sequestration was based on the studies of Montero et al. (2020). Knowing carbon storage (in both brush and canopy strata), CO_2 price and vegetation resilience, carbon sequestration losses could be representing by updating the economic value over the years necessary for restoring the original vegetation (Table 6). For further details, please consult Molina et al. (2019a). CO_2 price is considered as the price of fixing a ton of carbon based on the value it acquires on the carbon credit exchange (European CO_2 trading system, https://www.sendeco2.com/es/).
Currently, SEVEIF model only consider carbon fixation of trees and shrub in the aboveground parts of them and in their roots. However, it doesn't consider the carbon in the soil, neither the pyrogenic carbon gained by the ecosystem due to wildfires (Santín et al., 2015; Santín et al., 2016). As essential role in carbon sequestration, so further studies and SEVEIF improvements should include soil carbon sink.

3.1.2.2 Soil erosion

The assessment of erosion impacts requires an integrated approach based on potential erosion and vegetation resilience. Potential erosion is calculated using the Universal Soil Loss Equation (Wischmeier and Smith, 1978) using pre-fire and post-fire scenarios. A comparative analysis allows us to find erosion differences (t/ha) between scenarios. The erosion rates vary according to vegetation cover, fire intensity, soil, topography, and climate. When fire occurs, vegetation cover is usually strongly affected. Restoration time (number of years needed for recovering the vegetation cover) is directly related to the type of vegetation and ecosystem structures burned (Whelan, 1995; Brown and Smith, 2000). The economic damage can be represented by updating the urgent protection costs (real restoration planning in fires of Southern Spain) over the years necessary for natural cover (Table 6). For further details, please consult Molina et al. (2009).

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3.1.2.3 Endangered or flagship fauna species

The fire impact on endangered or flagship fauna species depends on the species, home range, food chain and the size of the wildfire. One of the most difficult challenges is to estimate the economic fire impacts on this ecosystem service. SEVEIF model suggests the use of two approaches: the assessment using specific European recovery programs and the assessment using contingent valuation. In the first approach, it is assumed that the cost of recovery programs is a real value paid by the population for species diversity. In the second approach, losses are calculated depending on the annual conservation value from these two methodologies and updating the annual species value over necessary for food and shelter restoration (Table 6). The real impact on endangered species is estimated as the product between potential losses and habitat degradation due to its food chain declination. Restoration time regarding this resource is considered as the number of years needed for the restoration of the base of endangered fauna species food chains. For further details, please consult Molina et al. (2019b).

3.1.2.4 Landscape and leisure services

The economic value of landscape is related to the landscape quality based on social preferences measured by DELPHI method. The conversion of landscape quality to economic values can be made using indirect approaches through the cost travel method or the contingent valuation. Knowing annual use value (willingness to pay or consumer surplus) and vegetation resilience, landscape services can be estimated by updating the economic value over the years necessary for landscape restoration (Table 6). Restoration time in leisure services is considered as the number of years necessary for restoring the original number of tourists. Social opinion (panoramic photograph) was used to identify the reduction in the number of visits based on different fire intensity levels. For further details, please consult Molina et al. (2017).

3.1.2.5 Non-use or existence services

People express concern about the degradation of a particular landscape they have never seen before and will not visit. The assessment difficulty lies in the market in which the participants will regard donation as a conservation payment method. Contingent assessment can be used to estimate willingness to pay for landscape conservation. Knowing this willingness to pay and vegetation resilience, existence service can be estimated by updating the economic value over the years necessary for landscape restoration in case of wildfire occurrence (Table 6). For further details, please consult Molina et al. (2009).

The economic assessment algorithms for the regulating, support and cultural services included in SEVEIF model are detailed below (Table 6). These mathematical algorithms are applied in the territory through a GIS, identifying and distributing, previously, each of the natural resources in the territory.

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Table 6: Mathematical algorithms for regulating, support and cultural services

Ecosystem service	Mathematical algorithm	Resource condition	Source
Carbon storage	L_{car} = 3.67*[CS*Pc + AS*Pc *[((1 + r)^y)-1)/(r*((1 + r)^y))]	Forests and treeless areas	Molina et al., 2019a
Soil erosion	L_{eros} = V* [(1 + r)^(n − 1)/(r*(1 + r)^n)]	Forests and treeless areas	Molina et al., 2009
Endangered or flagship fauna species	L_{endag} = V* [(1 + r)^(n − 1)/(r*(1 + r)^n)]	Presence of endangered animals	Molina et al., 2019b
Landscape and recreational resources	L_{lands} = V* [(1 + r)^(n − 1)/(r*(1 + r)^n)]	Forests and treeless areas	Molina et al., 2019c
Non-use or existence value	$L_{non-use}$ = V* [(1 + r)^(n − 1)/(r*(1 + r)^n)]	Forests and treeless areas	Molina et al., 2009

where "L" is the maximum fire impacts or losses (€/ha), "CS" is the carbon stock when the fire occurs (m^3/ha), "P_c" is the fixation price of carbon dioxide (€/tCO_2), "AS" is the annual volume increment on carbon storage (m^3/ha), "r" is the compound annual interest rate based on restoration time, "y" is the time or years remaining in the harvesting rotation or senescence age (difference between rotation length and age), "V" is the annual resource value (€/ha) and "n" is the estimated number of years until vegetation recovery.

3.2 Depreciation ratio estimation

Determining fire impacts in ecosystem services, both provisioning and regulating, support and cultural services, requires knowing the remaining value of the resources, i.e., the "net change in the value of the resources." The net value change is determined by the fire-line intensity which is directly related to flame length. Expressing the depreciation ratio in terms of a percentage value responds to a greater simplicity required by end-users. A high fire intensity level is related to greater fire economic impacts. The depreciation ratios for each resource and FIL were tested on larges wildfires occurred in Andalusia during the period 1993-2021 and the scientific results of FIREMAP, SINAMI, INFOCOPAS and GEPRIF projects (more information in www.labif.es).

SEVEIF model incorporate the net-value change associated with fire intensity (Rodríguez y Silva *et al*. 2012), through field inventories in Spanish large wildfires, comparing burned areas with unburned control areas for each of the ecosystem services. Any fire impact is expressed as the product between the maximum fire impact or economic losses (section 3.1) and depreciation ratio (%) using Table 7.

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Table 7: Depreciation ratio (%) of each resource based on FIL

FIL	L_{timber}	L_{fruit}	L_{past}	L_{hunt}	L_{car}	L_{eros}	L_{endag}	L_{lands}	L_{ler}	$L_{non-use}$
I	+1.5	+2	+12	+4.5	-5	-10	+2.5	-2.5	-2.5	-1
II	-8	-5	+12	-20	-16	-15	-28	-10	-8	-8
III	-17	-10	-65	-45	-40	-25	-45	-25	-15	-19
IV	-39	-20	-85	-65	-60	-45	-60	-61	-55	-46
V	-58	-45	-100	-85	-85	-65	-80	-72	-65	-54
VI	-83	-65	-100	-95	-95	-95	-90	-92	-85	-69
VII	-90	-75	-100	-100	-100	-100	-100	-92	-92	-69

The last step in the methodology, once fire impacts of one ecosystem service was completed, is the sum of the different resources that appear in each pixel or burned area. SEVEIF model could provide individual damage of each resource or the total impacts assessment.

4 On-line SEVEIF tools for fire impacts assessment

The Laboratory of Forest Fire (LABIF) of University of Córdoba has implemented support tools to the valuation of economic fire impacts. AppERIIF and Visual-SEVEIF allow us to value the fire damages using the proposed SEVEIF model. Both tools have a simple interface with seven modules to respond dynamically and effortlessly to end user needs. These support tools could be used to prevention, suppression, and post-fire approaches, mainly in budget allocation and judicial economic reports. Both tools are alternative one to the other, that is meant, could be used equally. However, the only difference between them is that AppERIIF is an analytic tool and the product is not geospatially referenced (users should do it manually with a GIS if they are interested in have the result distributed in the territory). Nevertheless, Visual-SEVEIF produces geo-referenced data, requiring consistent spatial mapping inputs to be implemented.

4.1 AppERIIF

AppERIIF can be downloaded free (**www.labif.es/software/**). This software or economic tool has two versions: laptop or desktop application and smartphone application (App). Firstly, when end-users access to the application, they should select the ecosystem services that would like to include in the assessment. This option is available from the pop-up menu at the top left of the screen (Figure 2). In this menu, language (English or Spanish) can be also selected.

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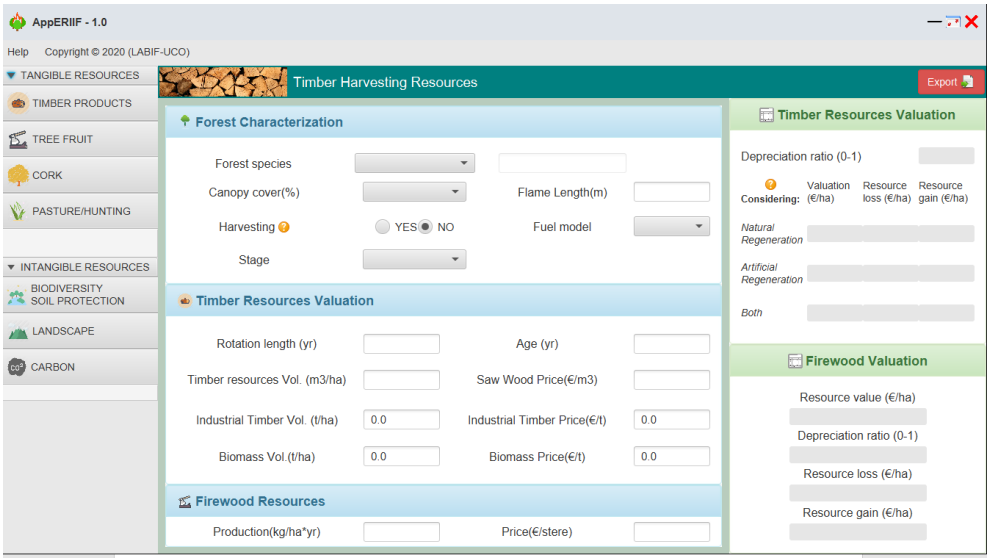


Figure 2: AppERIIF interface

The interface is divided for all ecosystem services in two sections. The first part is related to the inputs or data necessary to perform the assessment; and the second one is associated with the outputs, fire impacts. Fire impacts are expressed as "resource loss" (negative impacts) and "resource gain" (positive impacts) (Figure 2). The inputs and outputs can be exported in csv format using the tool located at the top right of the screen.
AppERIIF has seven independent modules:

- Timber products resources: timber, biomass, and firewood resources
- Tree fruit resources: pine nut, chestnut, and acorn
- Cork harvesting resource
- Pasture and hunting resources
- Endangered or flagship fauna species and soil protection resources
- Landscape goods: recreation, landscape, and non-use resources
- Carbon fixation resource

4.1.1 Timber resource module

End-users can use default settings for variables though the forest characterization (forest species, canopy cover and stage) (Figure 3). Although AppERIIF includes default values of rotation length, age, timber and biomass volumes and timber and biomass prices, end-users can modify these values if they are not considered appropriate for the study area. Timber resources valuation is based on the harmonization between American (natural regeneration) and Spanish (artificial regeneration) approaches. In this sense, the software requires the information (yes or no) about the importance of timber harvesting in the burned area (Is timber harvesting one of the main resources of the forest?). The relative weight of American and Spanish valuation approaches (Table 3) varies based on this question (Rodríguez y Silva et al., 2012).

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End-users cannot modify the outputs at the top right of the screen because they are justified on previous mathematical algorithms (Tables 4 and 6). Resource loss and resource gain are estimated according to resource value and depreciation ratio. This ratio depends on the flame length that should be included by users. Mean depreciation ratios on timber products for each Fire Intensity Level (FIL) or flame length were calculated using field inventories in ten large wildfires in Spain (Rodríguez y Silva et al., 2012).

At the bottom of the screen, firewood resources can be found. This type of resources requires annual production and resource price (Figure 3). Firewood is a periodical resource, but the mathematical formulation includes annual production (Table 3). In this sense, periodical production should be expressed as annual value by a simple division between total production and the number of years. The firewood price is usually expressed as "stere" (metric unit of volume equal to one cubic meter).

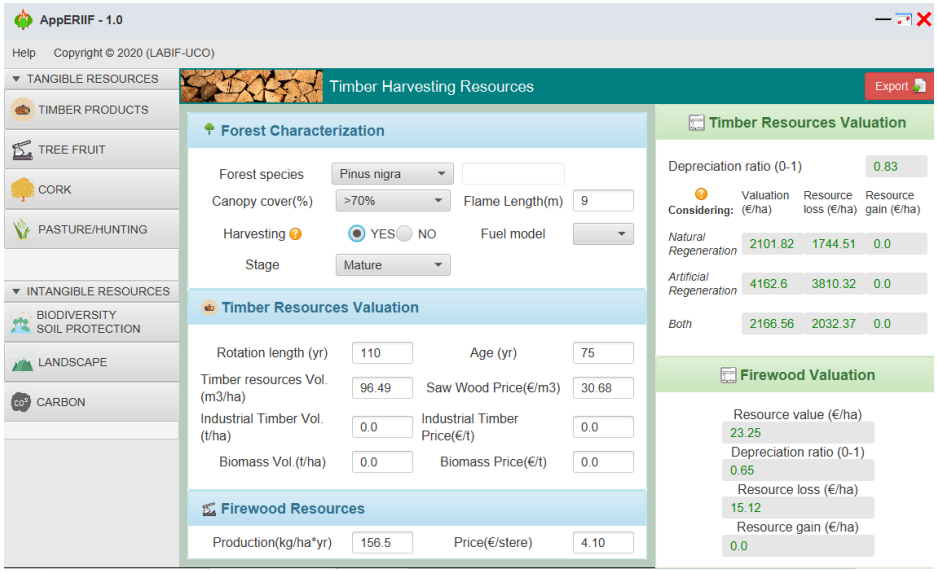


Figure 3: Timber resource module of AppERIIF

4.1.2 Tree fruit resource module

There are two different parts in this module, the first one is to input variables (at the top of the screen) and the second one is to output generation (at the bottom of the screen) (Figure 4). Although the application includes three tree fruits, the mathematical formulation is the same for all tree fruits (Table 4). After inserting forest species, stand development stage and canopy cover, a default annual production and resource price can be found. These default values can be modified by the user according to the burned area characteristics. In this sense, special attention should be given to acorn price to swine production (Molina et al., 2011). Finally, flame length is required to estimate depreciation ratio according to large wildfires experiences in Southern Spain (Molina et al., 2011). When incorporating flame length, depreciation ratio, resource loss and resource gain, are calculated. End-users can export the results in a similar way to timber resources.

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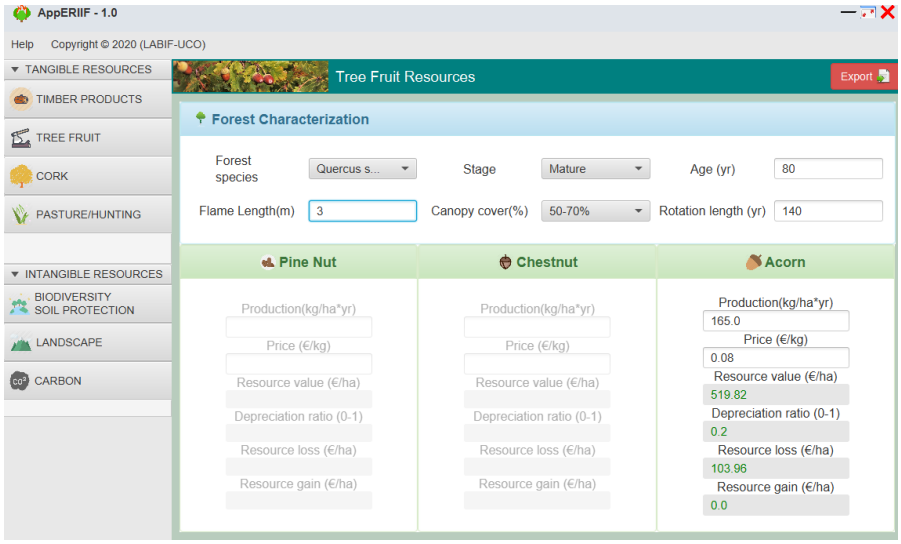


Figure 4: Tree fruit resource module of AppERIIF

4.1.3 Cork harvesting module

In this module, the user should include forest species (*Quercus suber*), canopy cover, stand development stage, rotation length and tree age showing default values of cork harvesting, dry weight, harvesting cycle, cork price and quality cork (Figure 5). These values can be modified according to user´s requirements. The depreciation ratio and resource loss require the incorporation of flame length and cork age (less or more than 6 years). Therefore, the depreciation ratio is higher in recently harvesting stands due to the reduced bark thickness (Molina et al., 2009). End-users can export the cork harvesting impacts in csv format.

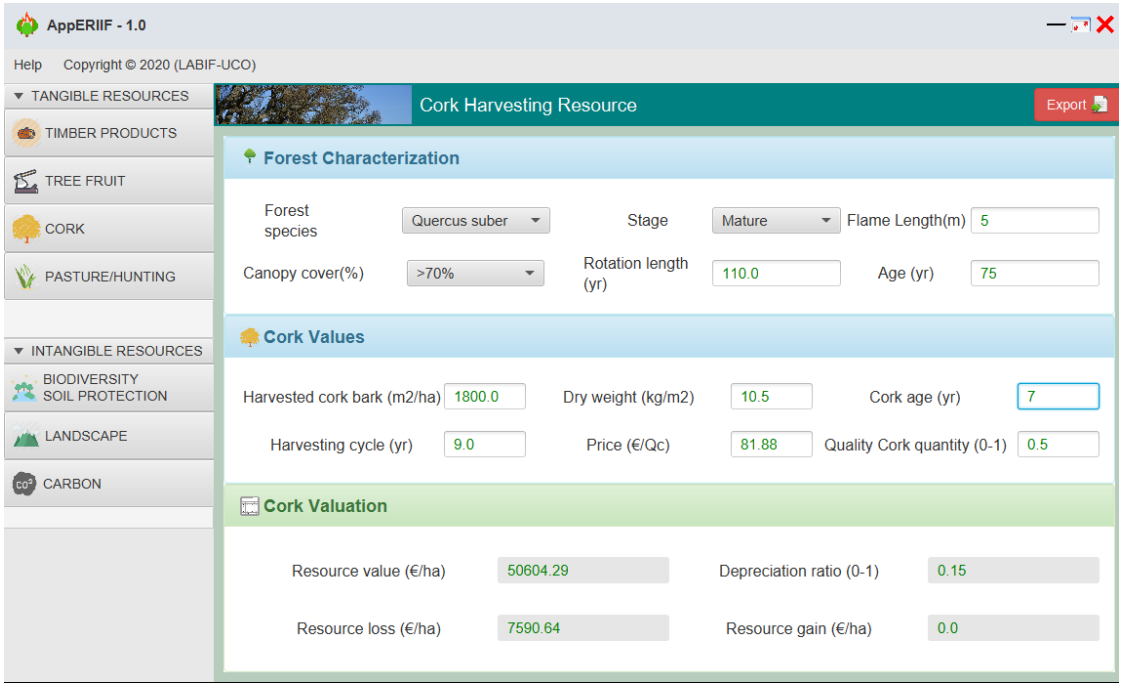


Figure 5: Cork harvesting module of AppERIIF

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4.1.4 Pasture and hunting module

On the one hand, the pasture assessment requires the incorporation of nutritive value of pasture and hay price or substitute product (Figure 6). Post-fire pasture exclusion also affects the resource loss due to the number of years without livestock exploitation (Molina et al., 2011). On the other hand, hunting resource requires the characterization of the vegetation in game reserves. After selecting vegetation type or fuel model, annual profit, and reproductive stock (Table 3) are estimated by mean values of field captures in Spanish studies (Zamora et al., 2010). However, these default values can be modified by the user based on hunting plans and technical reports. In both pasture and hunting resources, flame length is needed to estimate depreciation ratio, and therefore, resource loss and/or resource gain (Figure 6).

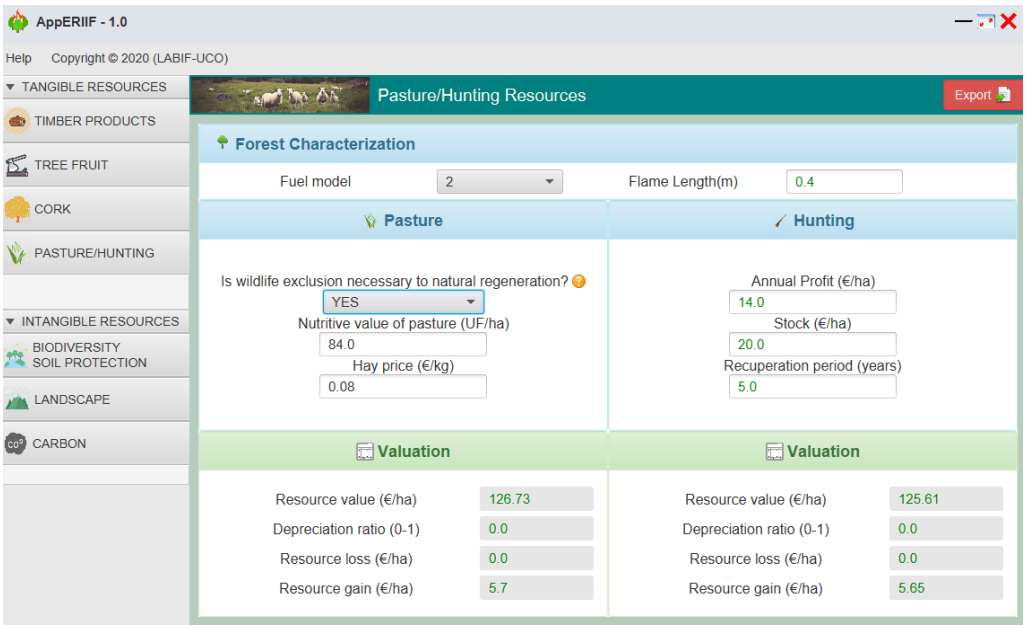


Figure 6: Pasture and hunting module of AppERIIF

4.1.5 Flagship fauna species and soil protection module

Regarding flagship or endangered fauna species, the user should identify the maximum level of protection according to the International Union for Conservation of Nature (IUCN) in the burned area: critically endangered, endangered, vulnerable and near threatened or least concern (Figure 7). For the economic assessment of this ecosystem service, the application used two approaches: the value of European recovery programs for flagship species (critically endangered) and the contingent valuation. A mean value or willingness to pay (contingent valuation) was estimated by each IUCN category using 231 questionnaires (Molina et al., 2019b). Fuel model should be also established due to the mean resilience time or number of years need to recuperate species food and shelter. Up to this point, only fauna species have been considered in the assessment, however, flora species are going to be included in further research considering the same methodology as for the implementation of fauna species.

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The soil protection depends on the rainfall, the soil erodibility, the slope length-gradient factor, the vegetation factor, and the support practice factor according to the Universal Soil Loss Equation (USLE). However, only vegetation factor (fuel model) is modified by the fire occurrence. The slope length-gradient factor also has a very important influence on runoff. For this reason, fuel model and slope are required by fire impact assessment. Mean economic values are calculated based on Andalusia experiences of urgent post-fire plans due to hydrological and hill-slope stabilization costs (Molina et al., 2009).

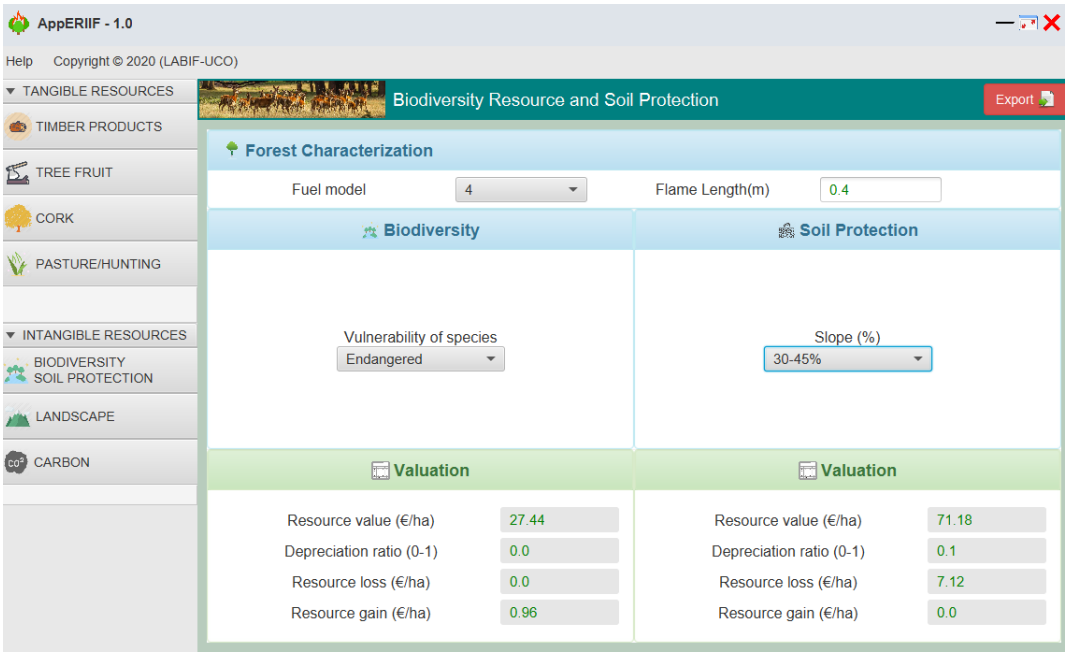


Figure 7: Endangered or flagship fauna species and soil protection module of AppERIIF

4.1.6 Landscape resource module

All landscape goods require information about vegetation characterization (fuel model) and the presence of natural protected areas. This module includes three ecosystem services: recreation, landscape, and non-use or existence value (Figure 8). After identifying fuel model, topographical characteristics (slope and slope aspect) and the presence of natural protected areas, a default annual landscape value is assigned based on a previous qualitative landscape evaluation (Molina et al., 2016). The final landscape valuation depends on the restoration time (number of years necessary for restoring the original landscape quality) and annual interest rate. For the recreation resource, the user should also identify if there are some population centers close to the burned area and its approximate population (no, < 200,000, 200,000-1,000,000 and > 1,000,000 inhabitants). Recreation valuation also need data about the presence of recreational paths (hiking, mountain-bike, and horse trails) and tourist infrastructure in the burned area. Finally, non-use resource valuation is based on landscape value, the presence of cities or villages and the presence of natural protected areas. If fire spreads to valuable landscape areas, existence values and fire impacts will be greater. Similar to other resources (previous modules), if the user changes flame length, depreciation ratio and resource loss are modified.

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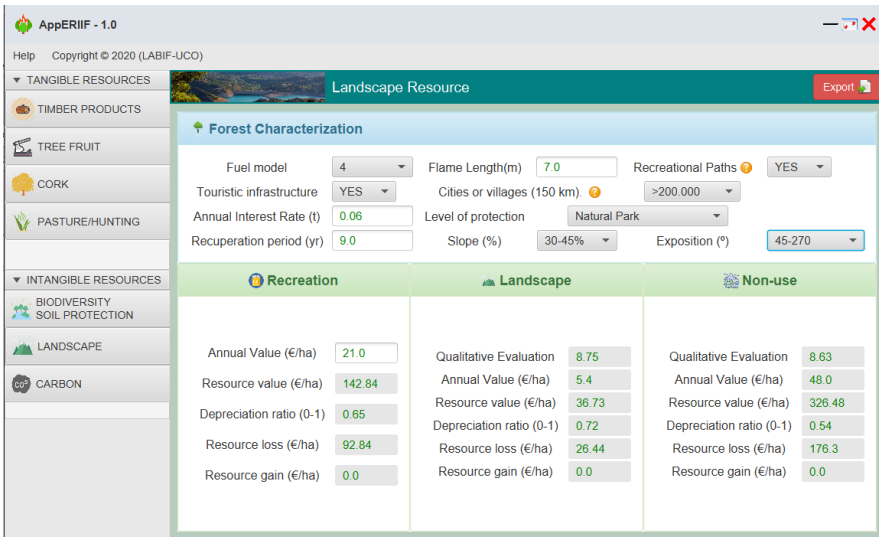


Figure 8: Landscape resource module of AppERIIF

4.1.7 Carbon fixation module

Information about forest characteristics (forest species, stand development stage, canopy cover, rotation length and age) is needed, showing default vales of timber volume, wood density, annual volume increment, biomass expansion factor, root-to-shoot ratio and CO_2 fixation price (Figure 9). All variables of the mathematical formulation are explained in detail from Molina et al. (2019a). In this sense, the user can modify the different variables of the mathematical formulation (Table 4) according to their own dataset. The default value of aboveground shrub biomass is adjusted by a mean value from each fuel model according to field inventories (Rodríguez y Silva et al., 2012), but it could be obtained from each study area. If only shrub valuation is considered, timber variables (volume and annual increment) should be 0. Finally, flame length modifies the depreciation ratio and resource loss (at the bottom of the screen).

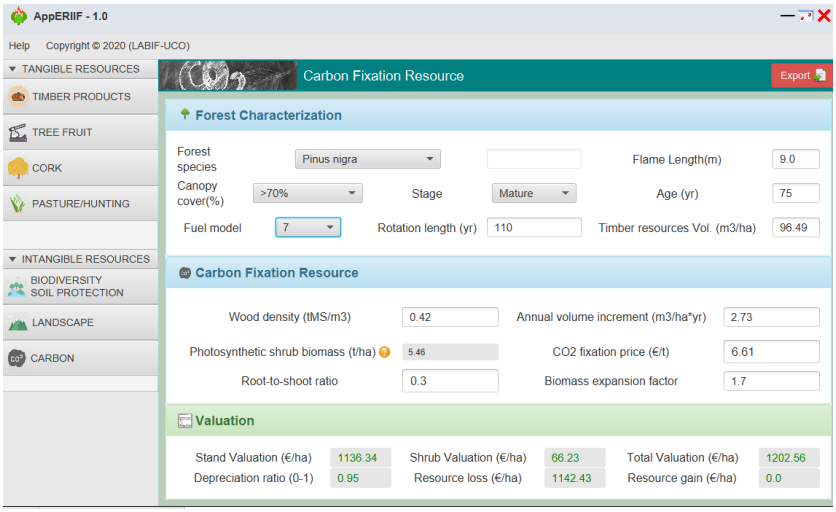


Figure 9: Carbon fixation module of AppERIIF

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4.2 Visual-SEVEIF

Visual-SEVEIF (Figure 10) can be downloaded free (www.labif.es/software/). Visual-SEVEIF (Rodríguez y Silva et al., 2013) simulates fire spread and fire impacts according to the natural resources characterization. The latest version, Visual-SEVEIF 4.1.2, has been successfully updated in these last few years with the support of FirEUrisk. Technical improvements aim to the valuation of consumer services and export options (output format).

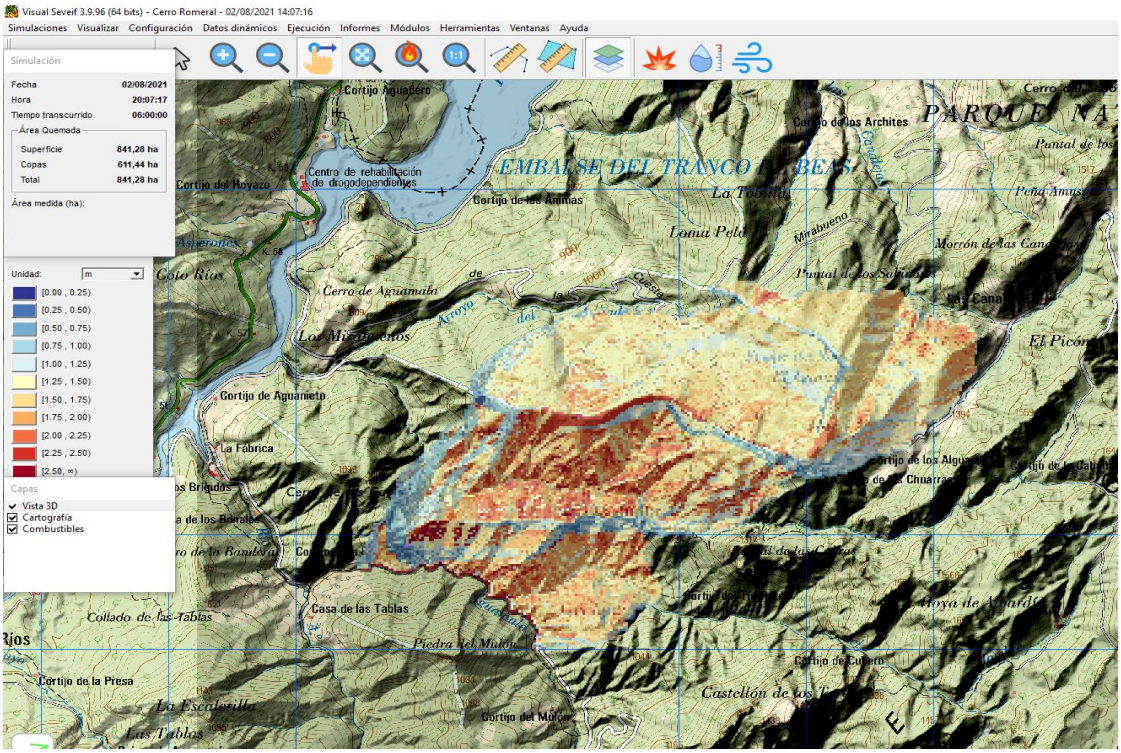


Figure 10: Visual-SEVEIF interface

Visual-SEVEIF integrates the same economic formulations as AppERIIF. In the first module, users should select the ecosystem services that would like to include in the assessment. The first module includes forest tree resources, such as timber products, non-timber tangible assets and carbon sequestration (Figures 11 and 12). In a similar way to AppERIIF, user can use default settings for variables though the forest characterization (forest species, canopy cover and stage).

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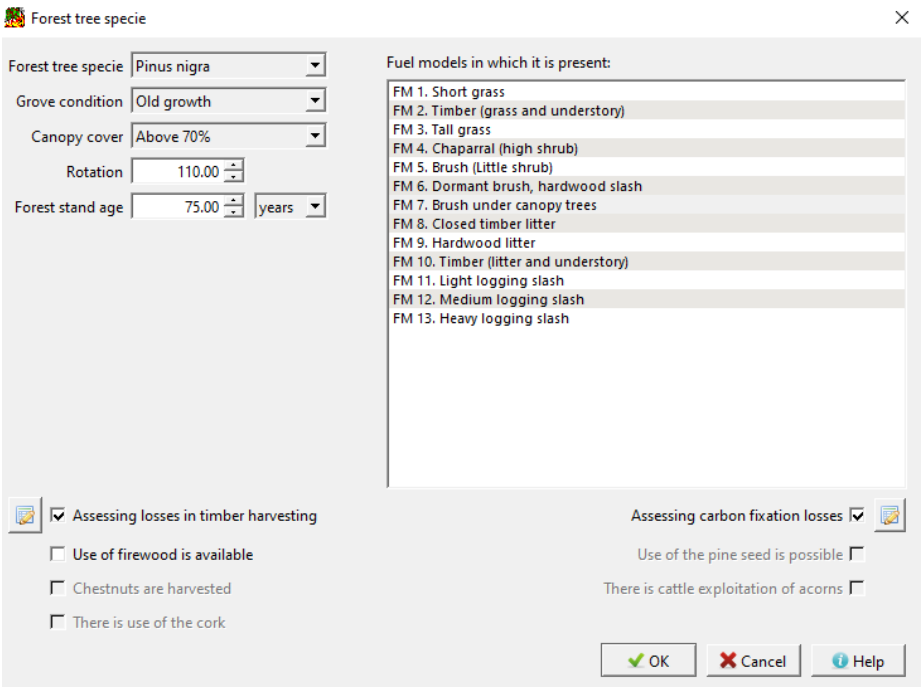


Figure 11: Forest tree assessment module

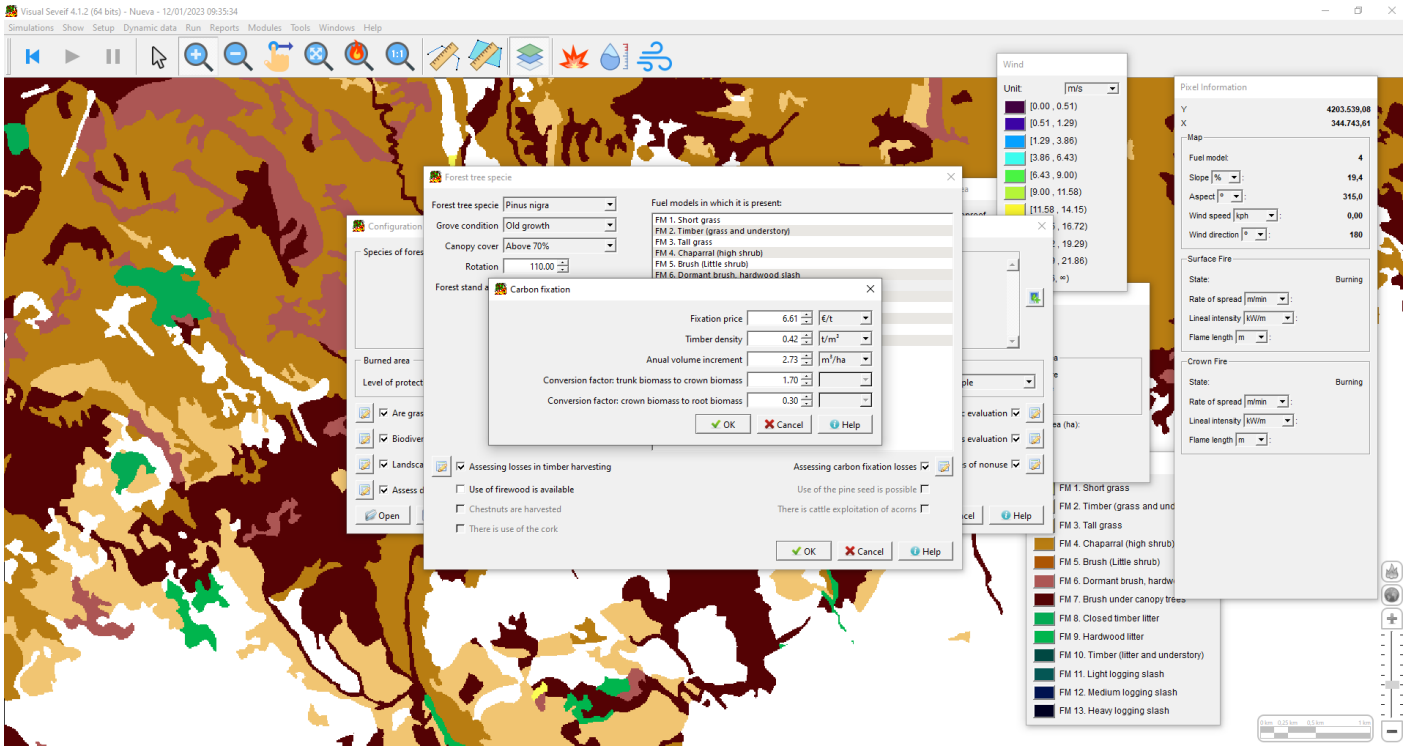


Figure 12: Carbon sequestration sub-module (this resource is included by forest tree module)

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Pasture and hunting resources (Figure 13), endangered or flagship fauna species (Figure 14) and landscape goods (Figure 15) resources have independent modules. The user can modify the default values according to the real condition of the study area.

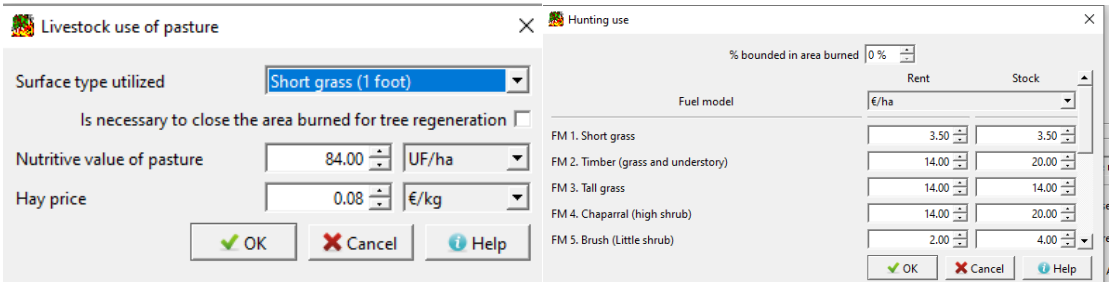


Figure 13: Livestock and hunting modules

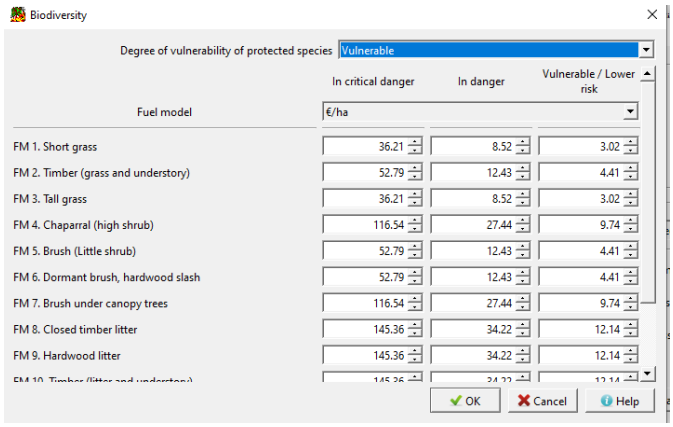


Figure 14: endangered or flagship fauna species module (default value to the presence of vulnerable species)

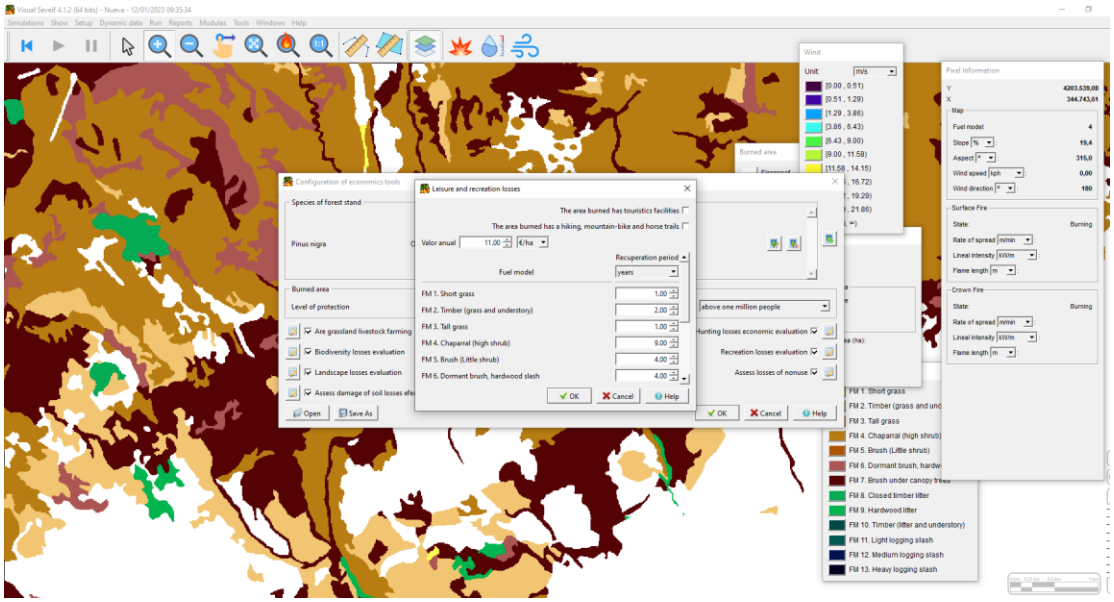


Figure 15: Landscape goods module

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5 Applications of the fire impact assessment methodology

Visual-SEVEIF model has applicability in different phases of the wildfire cycle. The methodology proposed in this deliverable is not just a theoretical methodology, but also, has a practical application. Visual-SEVEIF model as a way to assess potential losses of ecosystem services due to wildfires can be useful in different decision-making approaches as prevention, suppression and post-fire, predominantly regarding fuel treatment prioritisation, cost-efficient management, and budget allocation.

5.1 Fire prevention

The SEVEIF model can be applied even prior to the occurrence of the wildfire. In this case, most unfavourable meteorological conditions can be used to simulate potential or most unfavourable fire behaviour. Being aware of the potential fire behaviour, depreciation ratios for each resource could be represented. Once ecosystem services are assessed, potential fire impacts would be estimated based on the potential or most unfavourable depreciation ratio for each resource. The cartography of potential fire impacts could be used to prioritise fuel treatments in order to achieve a more cost-efficient budget allocation and to minimise fire damages (Rodríguez y Silva and González-Caban, 2010; Rodríguez y Silva et al., 2013). The area contraction factor (burned area/potential burned area) and impact contraction factor (fire impacts in burned area/ fire impacts in potential burned area) can therefore be compared using different forest management alternatives (Figure 16). Furthermore, the depreciation ratio in fuel-treated areas can be reduced due to a smaller flame length than in fuel-untreated areas. Complementary analysis of cost/benefit ratio should be used as an indicator to analyse the efficiency of the landscape management and prioritize fuel treatments. The cost is assumed to be the fuel treatment cost, meanwhile, the benefit is the reduction in the loss of resource value.

Timber Resources Valuation

Depreciation ratio (0-1): 0.89

Considering:	Valuation (€/ha)	Resource loss (€/ha)	Resource gain (€/ha)
Natural Regeneration	2101.82	1870.62	0.0
Artificial Regeneration	4162.6	3934.65	0.0
Both	1637.43	1556.0	0.0

Timber Resources Valuation

Depreciation ratio (0-1): 0.08

Considering:	Valuation (€/ha)	Resource loss (€/ha)	Resource gain (€/ha)
Natural Regeneration	2101.82	168.15	0.0
Artificial Regeneration	4162.6	2256.16	0.0
Both	1637.43	316.0	0.0

Figure 16: Comparative analysis between a control scenario (left) and understory clearing scenario (right)

5.2 Fire suppression

In recent years, the occurrence of simultaneous fires has been both relatively common and significant. The lack of suppression resources, the defence of settlements, and the need for concentrated efforts promotes leadership to take responsibility and to make decisions for the prioritisation of wildfires and sectors of the wildfire. Therefore, Visual-SEVEIF could be an interesting tool in terms of objectively prioritising the needs of each wildfire based on the potential

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damage. A more comprehensive analysis of wildfire consequences is required to improve our suppression effectiveness. Any of the Incident Command System implemented by fire agencies during wildfires suppression, should include a financial section that could justify economic firefighting needs with the help of this tool in real-time. Complementary analysis of cost/benefit ratio should be used as an indicator to analyse the efficiency of the suppression. The cost is assumed to be the suppression resource cost, meanwhile, the benefit is the reduction in the loss of resource value.

An example of fire suppression application is shown in Figure 17, where two simultaneous fires in Sierra Morena demonstration area have been simulated with Visual-SEVEIF. End-users can analyse and compare fire behaviour and potential fire impacts of both wildfires in order to facilitate decision making during firefighting and prioritize resource assignment to them.

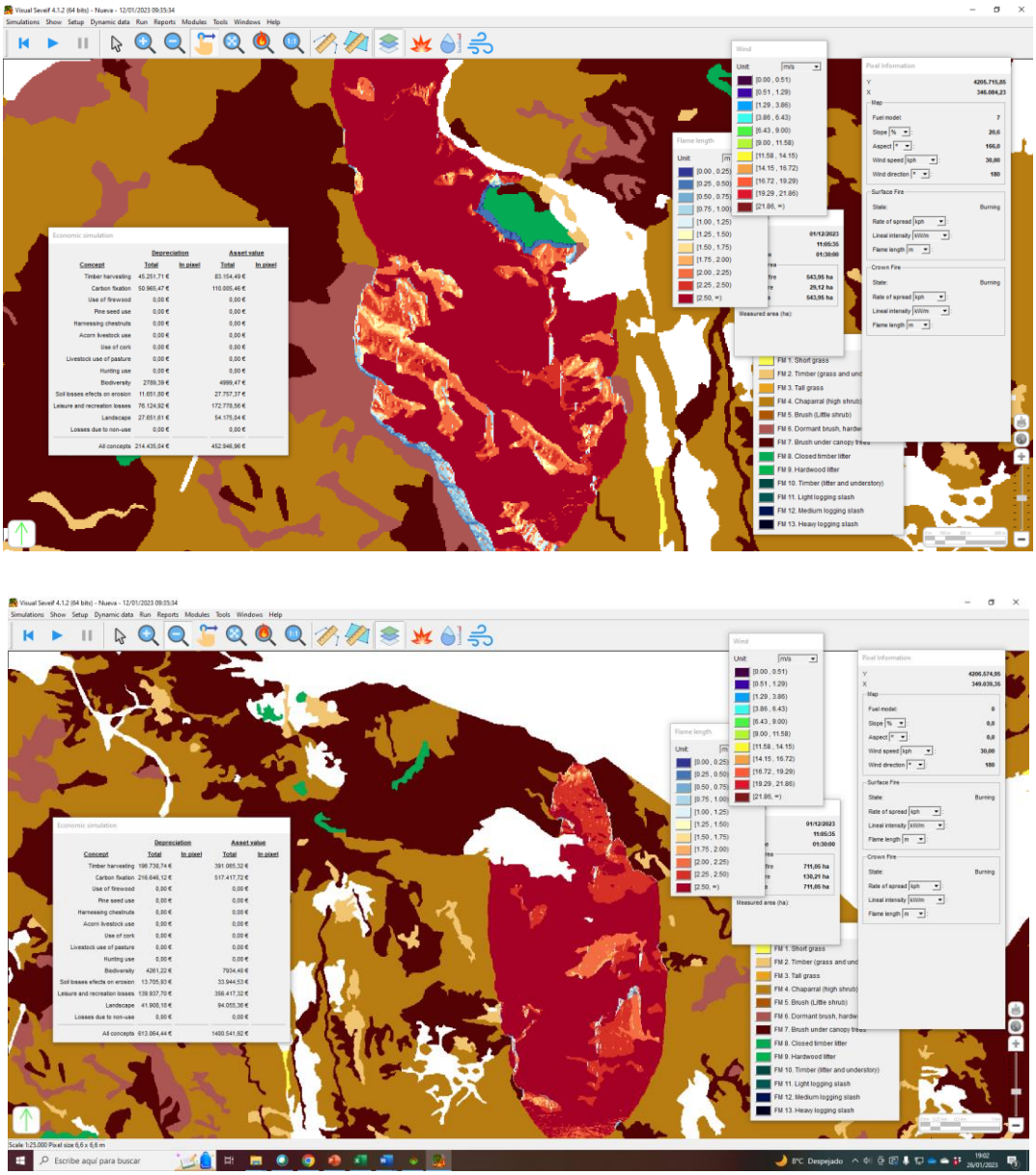


Figure 17: Visual-SEVEIF simulations of two simultaneous fires in Sierra Morena demonstration area

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5.3 Post-fire analysis

In the event of a large wildfire, agencies usually request a general technical report. This report includes meteorological conditions, fire behaviour, suppression resources and suppression limitations and difficulties. However, economic fire impacts are not usually included (some reports included affected houses but not natural resources). Visual-SEVEIF and AppERIIF could be used to incorporate a section of a general technical report in relation to economic damages on ecosystem services. The University of Córdoba Forest Fire Laboratory has already employed the SEVEIF methodology as a means by which to produce a general technical report of real large wildfires and judicial reports in Southern Spain and Chile.

6 Assessment of Ecosystem Services in PS4 Mediterranean (Spain)

This section is included as an example of SEVEIF model implementation in PS4 Mediterranean (Spain). Its application in the rest of the Pilot Sites (PS1 Northern Europe, PS2 Central-Eastern Europe, PS3 Mediterranean (Portugal), and PS5 Mediterranean (Greece)) is in process. Therefore, the potential losses due to wildfires in PS4 Mediterranean (Spain) are shown here.

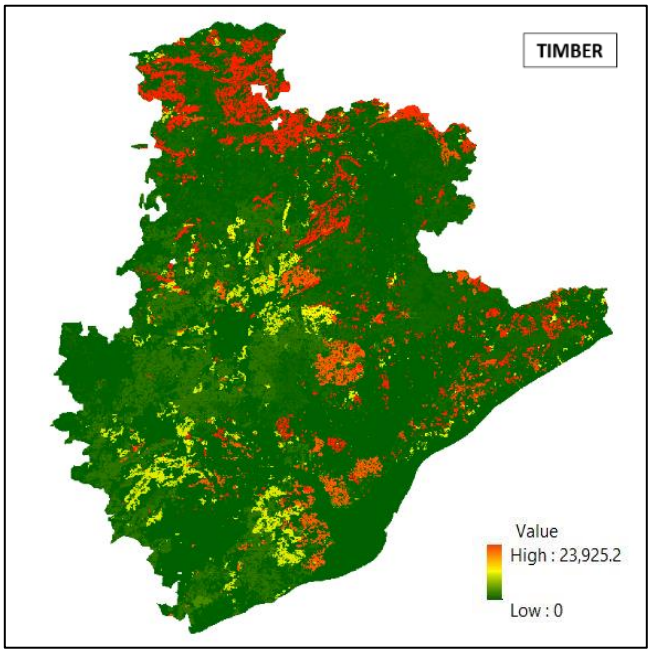
Timber, pine nuts, chestnuts, cork, pasture, hunting, carbon sequestration, erosion, endangered or flagship species, landscape and leisure were included in the assessment of ecosystem services in PS4 Mediterranean (Spain). It is worth noting that the timber price has been that of “Llotja de Vic”. We consider the use of current standing timber prices to have been a more interesting approach.

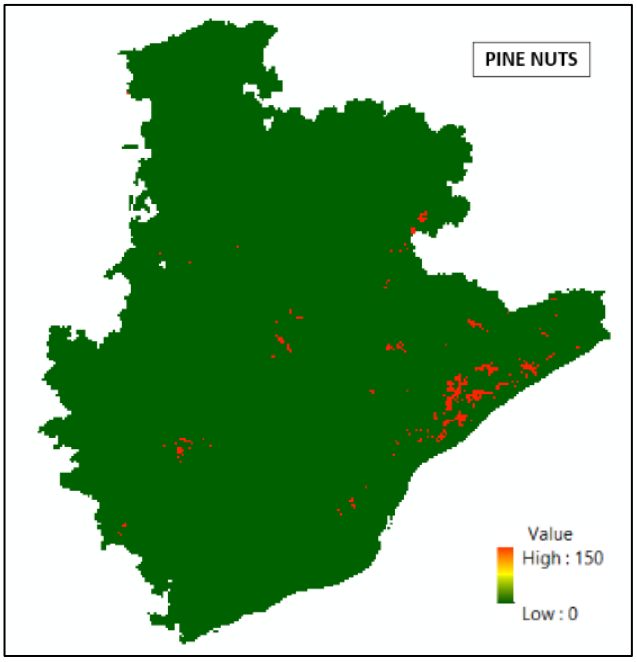
The SEVEIF model was applied based on fire behaviour data calculated by the University of Lleida. Flame length was estimated based on the most unfavourable meteorological conditions using the Basic Run. The random ignition approach of FlamMap was carried out based on the actual fire dataset distribution and size.

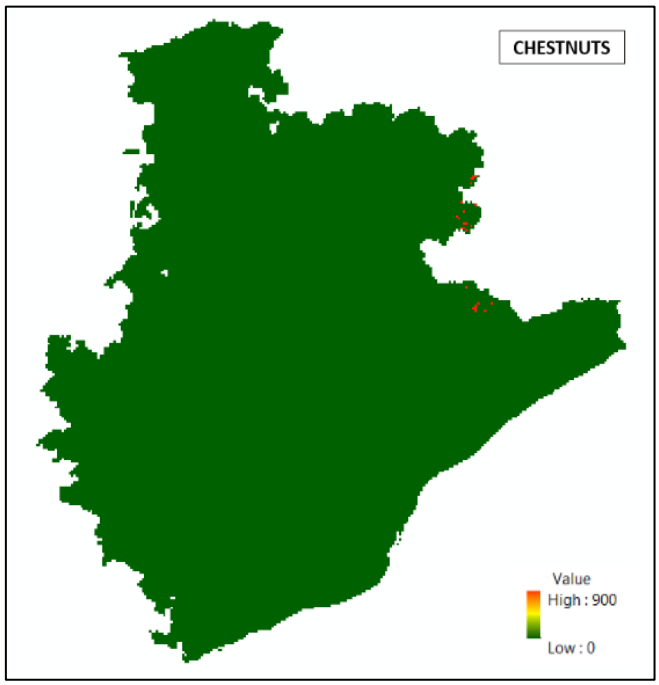
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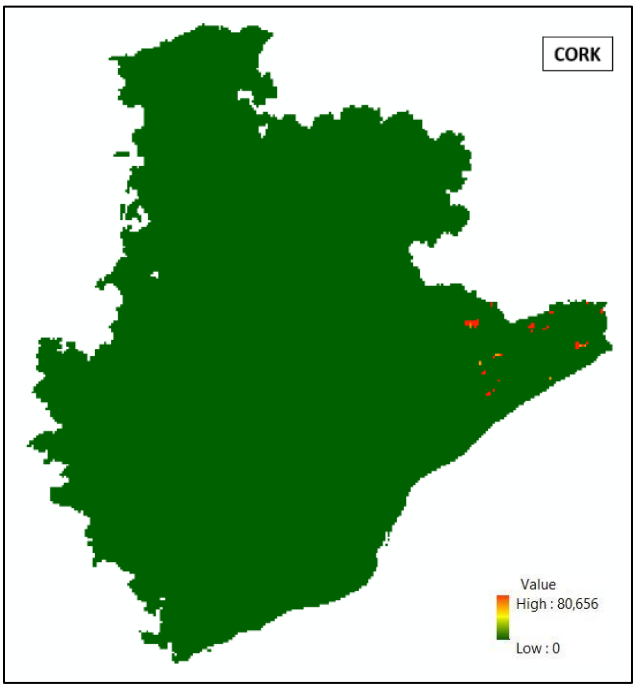
6.1 Pre-fire assessment of Ecosystem Services in PS4 Mediterranean (Spain)

The economic assessment of each ecosystem service identified in PS4 Mediterranean (Spain), coinciding with the province of Barcelona, is based on the mathematical algorithms and their input variables (Table 4 and 6). The results for each resource are shown below (Figure 18), expressed in €/ha.

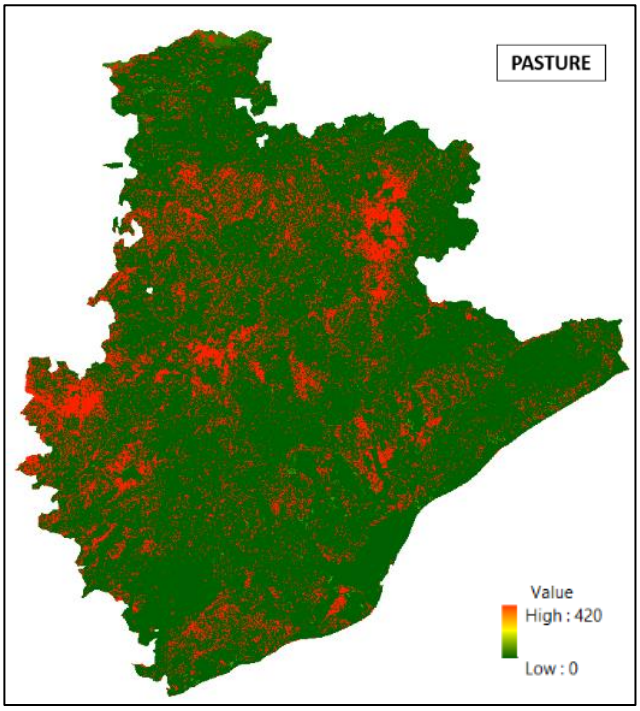


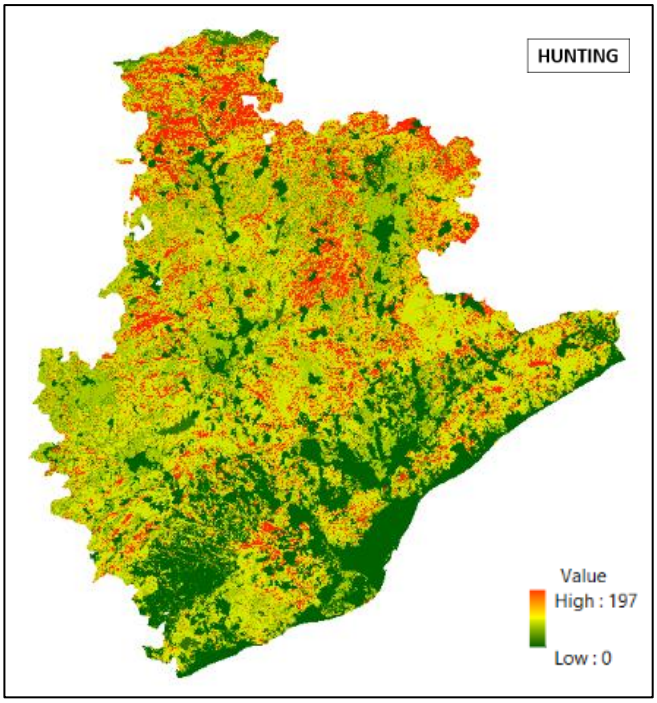


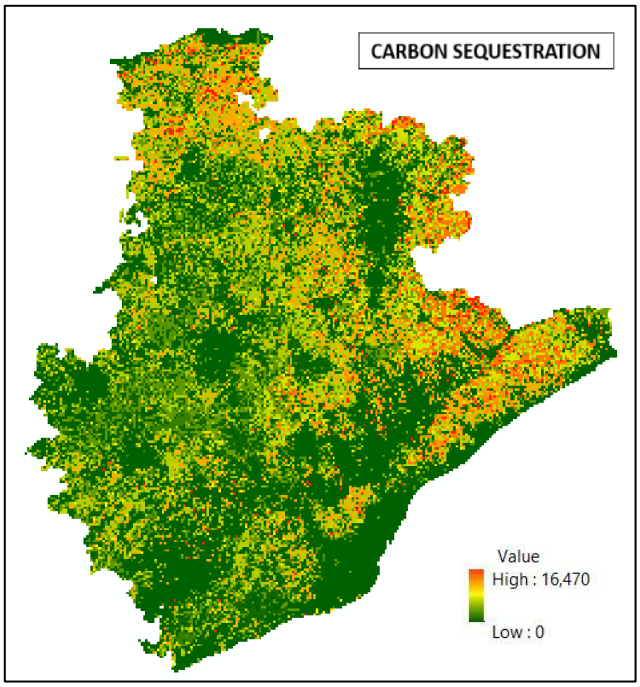


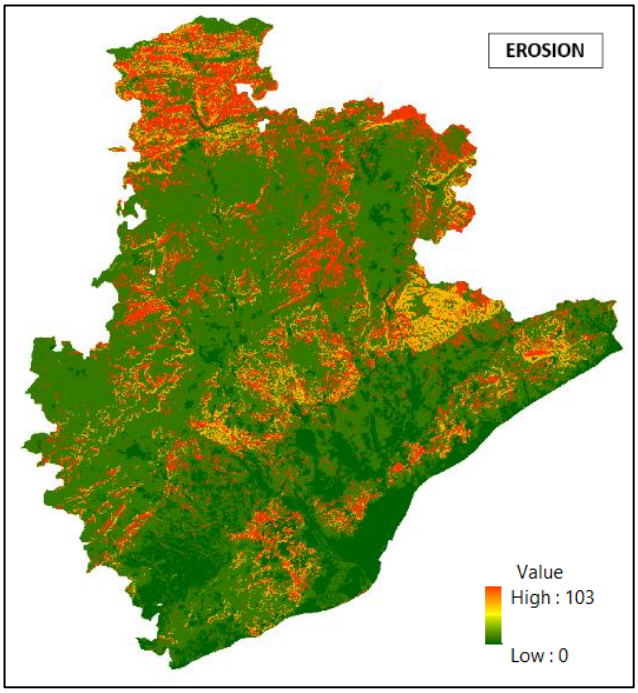


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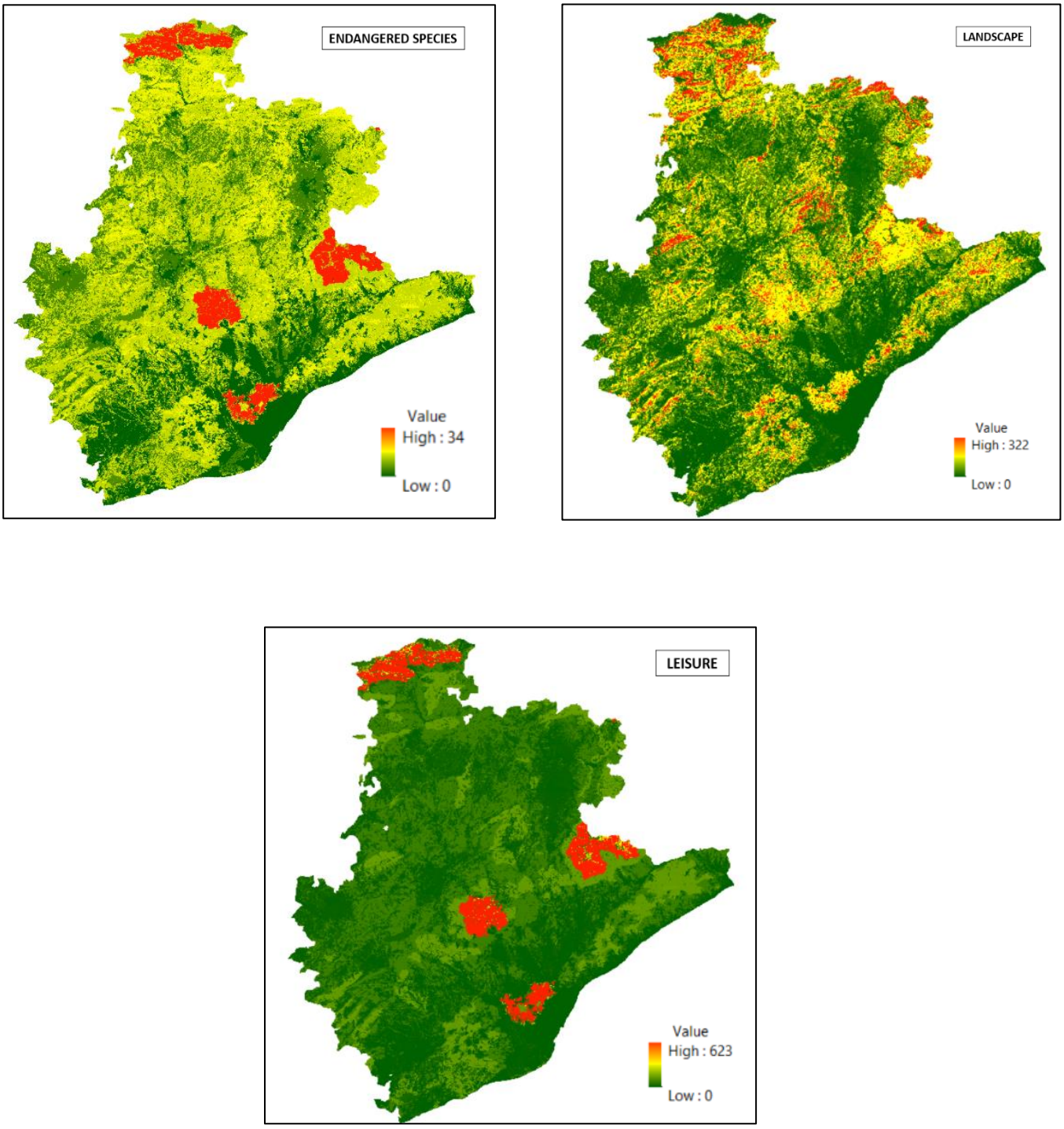


Figure 18: Pre-fire assessment of ecosystem services in PS4 Mediterranean (Spain)

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6.2 Depreciation Ratio (net-value change)

Fire intensity is directly related to flame length but this former behaviour variable is easier to identify in field inventories. SEVEIF model uses seven Fire Intensity Levels or categories based on simulated flame length (Figure 19). In this sense, fire behaviour data plays an essential role in depreciation ratio or loss the value of the ecosystem services. Fire impacts are expressed as the product between pre-fire value of each ecosystem services and its depreciation ratio (Table 7). The results can be found in the section 6.3 “Post-fire assessment of Ecosystem Services in PS4 Mediterranean (Spain)”.

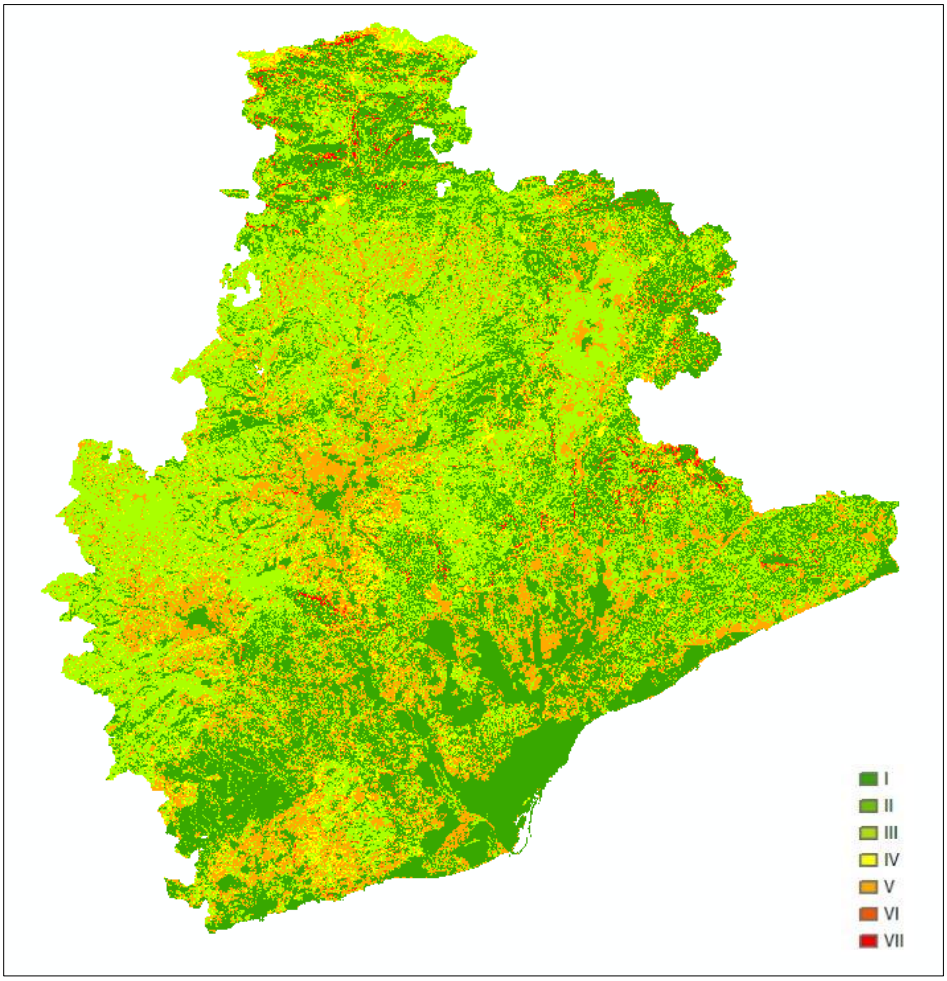
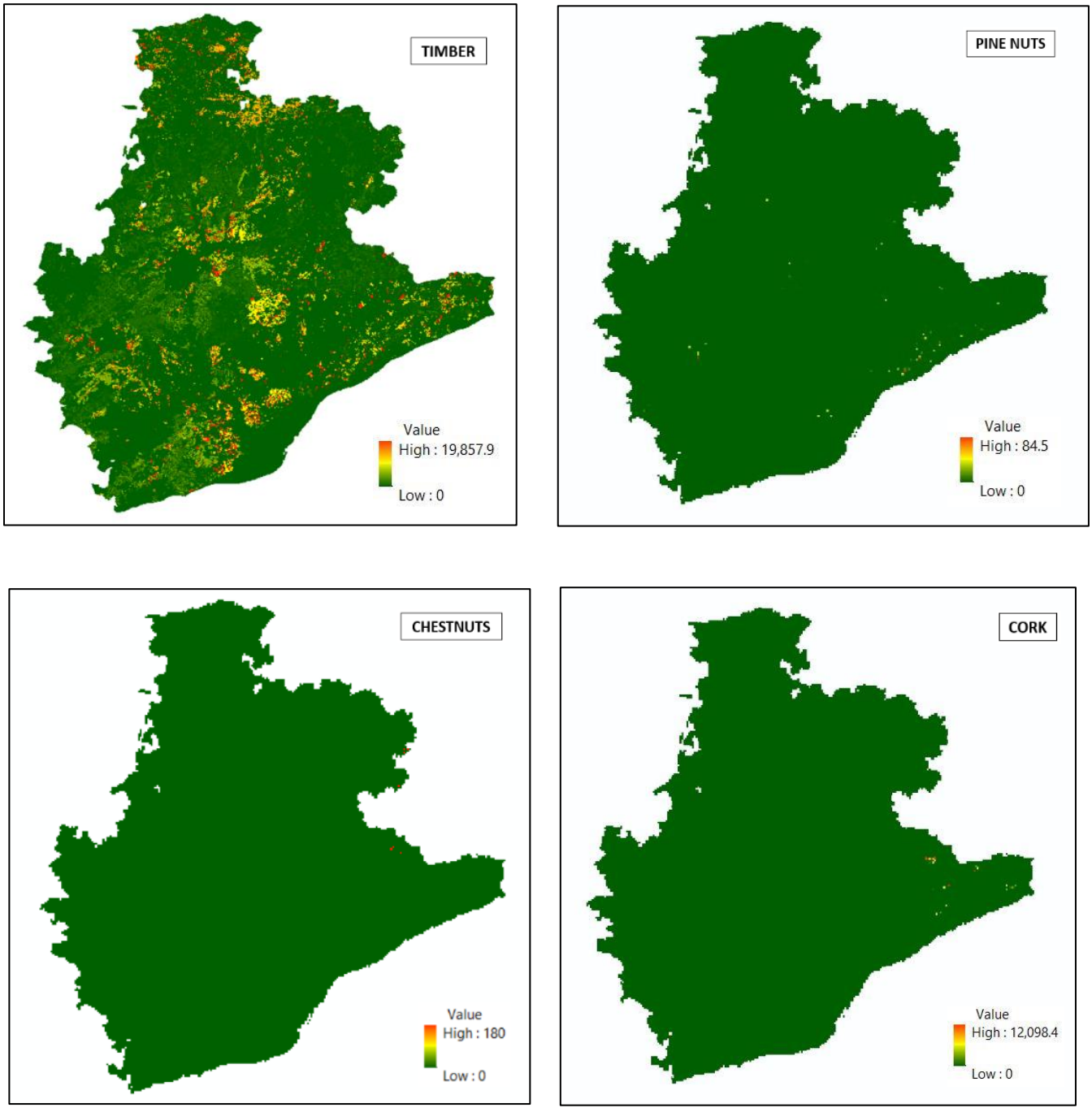


Figure 19: Potential FILs of PS4 Mediterranean (Spain)

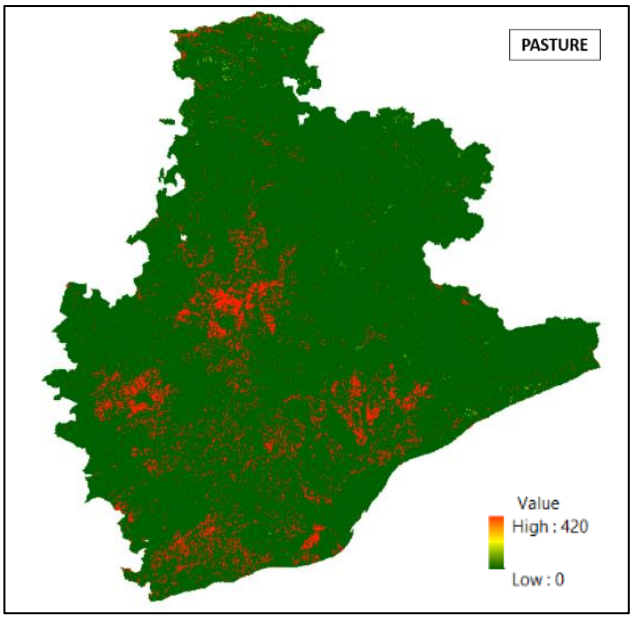
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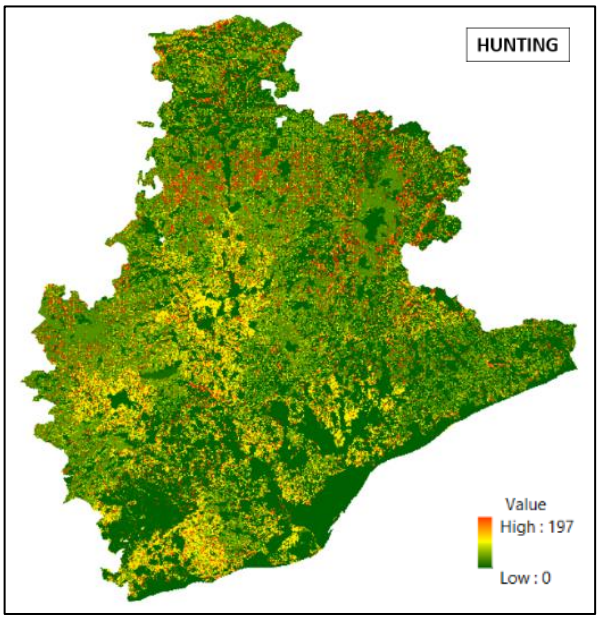
6.3 Post-fire assessment of Ecosystem Services in PS4 Mediterranean (Spain)

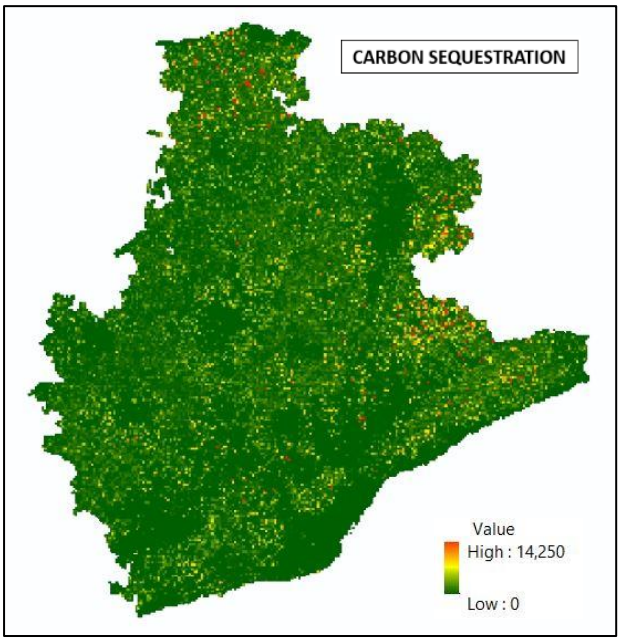
The post-fire assessment includes each ecosystem service identified in the territory that could be potentially affected by wildfires. The potential fire impacts in PS4 Mediterranean (Spain) are shown below (Figure 20), expressed in euros per hectare (€/ha). Finally, the sum of all potential losses on environmental services is presented as the Potential Fire Impacts in PS4 Mediterranean (Spain), expressed in €/km^2 (Figure 21), according to the spatial resolution of FirEUrisk project.

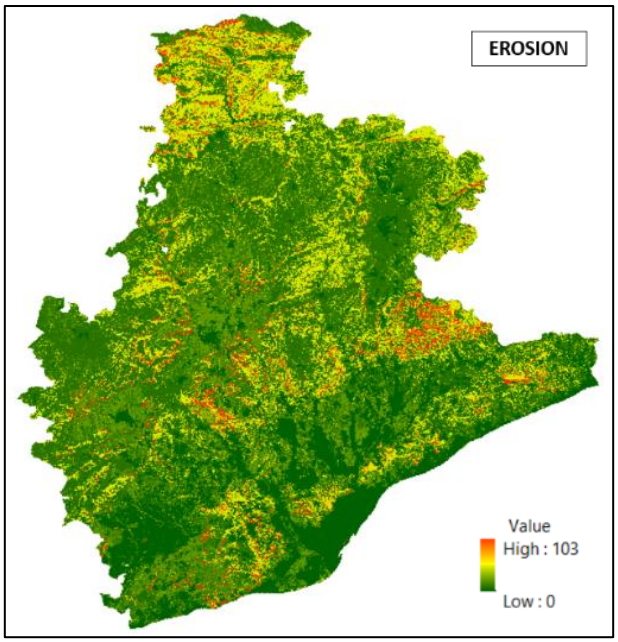


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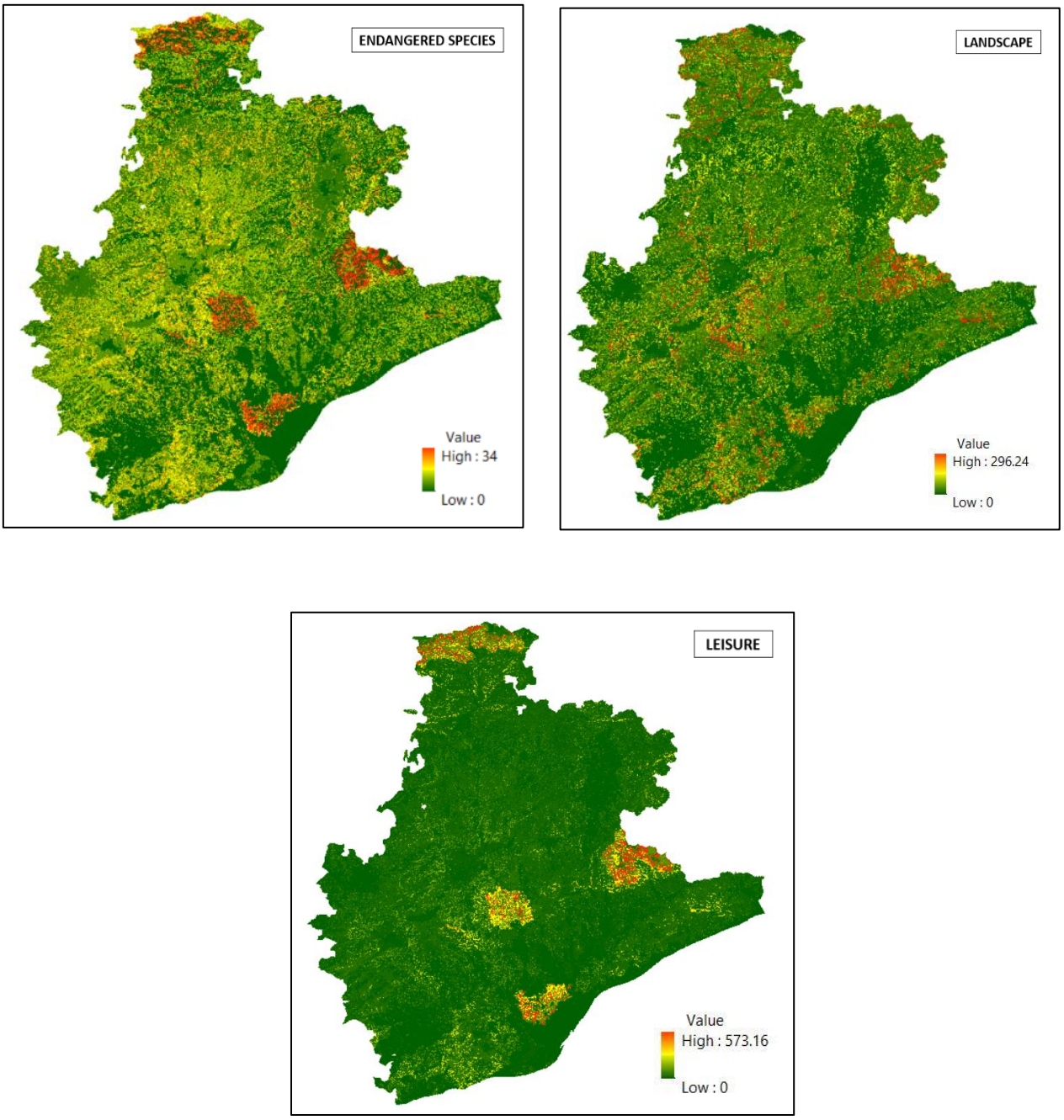


Figure 20: *Post-fire assessment of ecosystem services in PS4 Mediterranean (Spain)*

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Two final products for the Economic Assessment of Fire Impacts (Ecosystem Services) have been generated for PS4 Mediterranean (Spain):

- a raster with a spatial resolution of 100 meters (economic impacts in €/ha)
- a raster with a spatial resolution of 1,000 meters (economic impacts in €/km^2).

The products have been developed in this two resolutions according with the instructions of FirEURisk project.

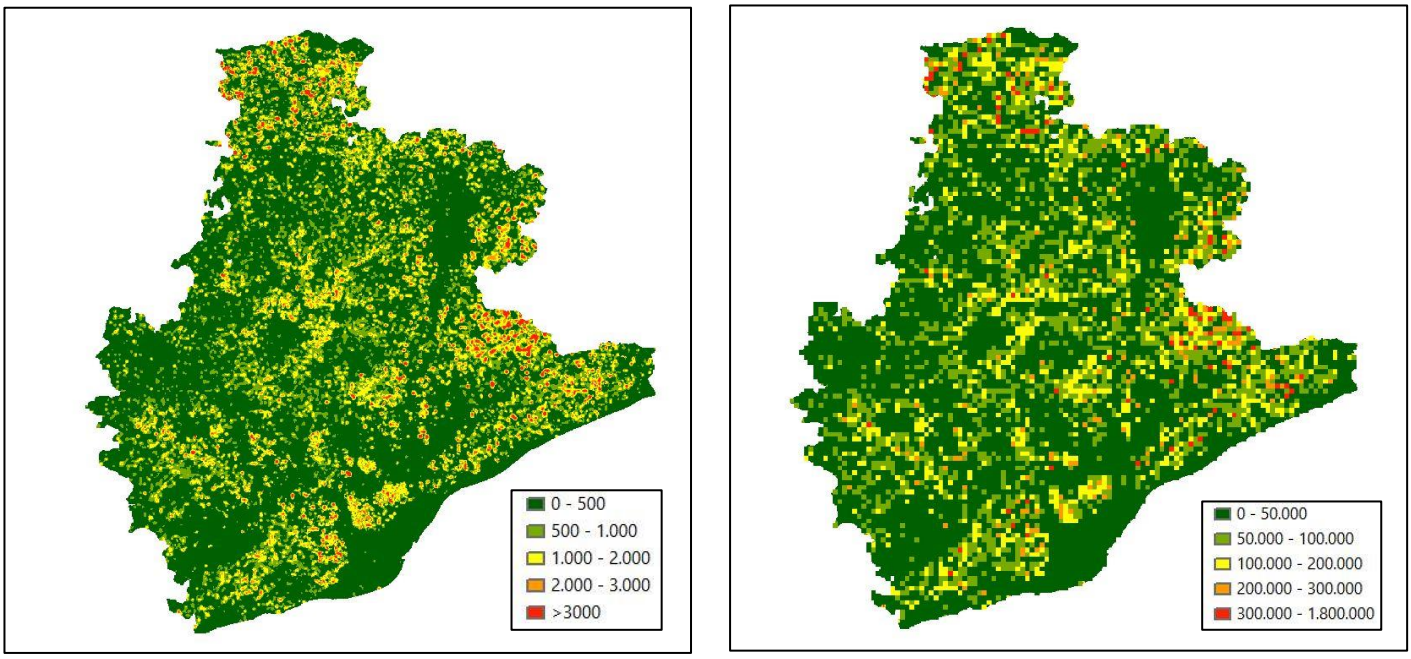


Figure 21: Assessment of Potential Fire Impacts in PS4, expressed in €/ha (left) and €/km^2 (right)

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To summarize, the economic losses (€) per ecosystem service type in the whole PS4 are shown below (Table 8).

Table 8: Economic losses (€/ha) per ecosystem service type in PS4 Mediterranean (Spain)

Ecosystem service	Economic losses (€)
Timber (L_{timber})	75,061,747.04
Non-timber products (L_{fruit}): Chestnut	15,576.71
Non-timber products (L_{fruit}): pine nut	43,921.11
Non-timber products (L_{fruit}): corck	3,048,275.01
Pasture (L_{past})	18,424,713.18
Hunting (L_{hunt})	13,624,411.07
Carbon storage (L_{car})	271,358,558.80
Soil erosion (L_{eros})	3,502,241.55
Endangered or flagship fauna species (L_{endag})	1,573,420.00
Landscape resources (L_{lands})	5,714,773.78
Recreational resources (L_{ler})	5,084,243.64
TOTAL	**397,451,881.9**

7 Limitations of SEVEIF model

SEVEIF model application presents the following limitations:

- Constraint in data availability. Inputs requirements are very demanding and this information is often not fully available or easy to find out.
- Difficulty in estimating the post-fire restoration time of some ecosystems without previous studies.
- High variability on tangible ecosystem services prices.
- Further studies regarding the determination of use and endangered species values are required, using indirect techniques, in protected areas outside the Mediterranean region. Current values have been established based on scientific studies in Spain and Chile.
- The SEVEIF model methodology has been tested in Southern Spain (Sierra Morena demonstration area), therefore, it is assumed to be fully applicable to other Mediterranean regions of Europe. Although replicability in other European ecosystems has not been proved yet, it could be applied through the customization of the variables, since the model allows the end user to modify the value that not fit with the studied territory.
- Although the depreciations based on FIL are standard values in Mediterranean environments, end-users can adjust these values if field information is available.
- Future studies should aim to include more types of ecosystem services that are not currently considered in SEVEIF model.

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8 Conclusions

- Wildfires are significant disturbances that cause economic damages to provisioning, regulating, support and cultural services. However, in some territories, predominantly those located in protected natural areas, the economic relevance of regulating, support and cultural services is even greater than provisioning ones.

- Global change leads to an increase in fire suppression difficulties, fire suppression costs and wildfires economic impacts.

- Assessing fire impacts on ecosystem services is a useful planning tool for forest and fire managers. Estimating economic impacts of wildfires helps to identify management alternatives in order to minimise fire impacts. SEVEIF model could help to analyse economic consequences (cost/benefit ratio) of fire policy changes. Areas with valuable ecosystem services would justify greater investments of wildfire protection programmes. Visual-SEVEIF and AppERIIF demonstrate the economic benefits under different forest management alternatives, facilitating the identification and delimitation of priority areas, known as “strategic management zones”.

- Fire impact assessment using software and/or mobile phone applications can be used for preventive approaches, such as the spatial optimisation of fuel treatments and budget allocation, suppression approaches, such as estimating the number of suppression resources or prioritising simultaneous wildfires, and post-fire approaches, such as completing general technical reports. Knowledge of the economic susceptibility of the territory (potential fire impacts) in the medium term facilitates the implementation of a more efficient fuel treatment spatial allocations.

- The SEVEIF model methodology has been tested in Southern Spain (Sierra Morena demonstration area) for the analysis of wildfire economic impacts on ecosystem services. Further validation should be made.

- There are two free downloadable tools (www.labif.es/software/) that enable users to employ the SEVEIF model. These support tools increase both the simplicity and flexibility of the model, enabling an extrapolation to different territories and spatial resolutions. According to the pilot sites of the FirEUrisk project, UCO will run the SEVEIF model to Northern Europe, Central-Eastern Europe, and the Mediterranean Basin (Portugal, Spain and Greece).

- Visual-SEVEIF and AppERIIF tools involve more than an economic assessment of natural resources, demonstrating the economic susceptibility to fire. Expressing the fire impacts in terms of net-value change responds to the need of including fire behaviour in economic assessment.

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