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Demand and supply of ecosystem services in a Mediterranean forest: Computing payment boundaries

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ABSTRACT

This study assesses the feasibility of a mechanism of payment for ecosystem services to improve the provision of ecosystem services by private forest owners. The range of the potential payment is defined by the opportunity costs of a change in forest management as the lower boundary, and by the willingness to pay of society for the improved supply of ecosystem services as the upper boundary. We assess these two boundaries in four hypothetical management scenarios for Aleppo pine forests in Catalonia (north-eastern Spain): (i) passive; (ii) active timber-oriented; (iii) biodiversity improvement; and (iv) wildfire prevention. The upscaling of the outcomes to the regional level shows that the value of the social demand covers the opportunity costs of the landowner. We argue that these figures prove the feasibility and likely acceptance of introducing a payment for ecosystem services based on an earmarked tax. This study represents an initial step for policy instrument design.

1. Introduction

Since the late 1960, the countries of the Northern rim of the Mediterranean have witnessed a decrease of traditional land use activities, resulting in a more homogeneous landscape with a steady accumulation of woody biomass (Gil-Tena et al., 2007), which has increased forest fire risk (Moreira et al., 2011) and reduced biodiversity (Torras et al., 2009). These changes in ecosystem structure and diversity threaten the dynamic supply of ecosystem services (ES) (Costanza and Daly, 1992:38). Thus, a set of relevant regulating, provisioning and cultural ES provided by Mediterranean forests are in risk of deterioration: soil protection (Shakesby, 2011), water quantity and quality (Cosandey et al., 2005), wood and non-wood products (De Miguel et al., 2014), recreation and aesthetics (Englin et al., 2001; Blasco et al., 2009).

Aleppo pine forests are spread along the highly populated Western Mediterranean coast and constitute a good example of such dynamics. In Catalonia (north-eastern Spain), similarly to other Spanish regions, Aleppo pine (*Pinus halepensis*) was intensively used in reforestation programmes (Pausas et al., 2004); moreover, this species rapidly colonizes abandoned agricultural fields and massively regenerates after moderate forest fires (Espelta et al., 2008). Yet, its slow growth, low timber quality and expensive mobilization reduce its economic profitability, and hence Aleppo pine forests are seldom sustainably managed, generating less ES.

Simultaneously, social demand for forest ES in the Mediterranean is steadily increasing (Croitoru, 2007). These demands are often disregarded in forest management planning, as most ES are not traded in conventional markets and hence do not enter landowners' financial calculations, based primarily on wood revenues.

To close the gap between ES supply and demand, payments for ecosystem services (PES) have emerged as a means of channelling monetary flows from ES beneficiaries to ES providers. Wunder (2005) defines PES as "*a voluntary transaction where a well-defined environmental service (or a land use likely to secure that service) is being 'bought' by a (minimum one) service buyer from a (minimum one) service provider, if and only if the service provider secures service provision*". PES main characteristic is the targeted financing of natural resource management actions towards meeting the social demand for ES. The popularity of PES schemes is such that they

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have been proposed in various forest policy processes in Spain (e.g. Valencian Territorial Action Plan, Catalan forest management plan instructions).

The aim of this paper is to explore the feasibility of implementing a PES scheme addressed to enhance the supply of ES by promoting management in private Aleppo pine forests in Catalonia. This translates into the following research questions:

1. Is there enough margin between PES boundaries for establishing a transfer? i.e. Do the social benefits of improving biodiversity or fire prevention exceed the private costs of such targeted management?
2. Does a hypothetical PES render positive social profitability and attractive financial indicators for the forest owner (FO)?

For that purpose we develop management scenarios for the status quo and ES supply and compare the private opportunity costs and the social benefits of changing scenarios, finally testing two hypothetical payments.

The novelty of this paper lies in the analytical comparison of ES demand and supply values within a PES design framework aiming at stimulating active forestry. This is rather singular, as typically valuation scholars do not take into account the costs of the scenarios provided to the interviewees, and forest management modellers and planners usually overlook the demand side.

Flores Velásquez et al. (2008) adopted a somewhat similar approach by combining valuation techniques with estimates of ES supply costs for recreational infrastructure and fire vigilance to control recreationists in public forests; i.e. PES additionality did not stem from changing forestry interventions but from new infrastructure. Daly-Hassen et al. (2010) compared private and social costs and benefits -including non-marketed forest benefits- of forestry actions (mainly afforestation) for watershed improvement in publicly-owned lands and discuss their potential implementation through a PES. Instead, our study focuses on private land managers, forestry changes and a different set of ES.

In contrast to studies analysing opportunity costs of land-use changes within a cost-benefit analysis framework, where bundles of ES are assessed within a total economic value framework (Kremen, 2000; Yaron, 2001; Strassburg, 2007), our study focuses on management changes, assuming the same land-use. In addition, active forestry in these studies implies a decrease in a set of ES, while in our case ES are expected to improve.

2. Methods

2.1. Ecosystem services and PES rationale

We follow the TEEB rationale (de Groot et al., 2010) considering changes in forest ecosystem structure to enhance biodiversity and wildfire prevention; these are proxies – or intermediate services using the framework proposed by Fisher et al. (2009) – for a bundle of final provisioning, regulating and cultural ES. Four ES lacking a specific market and supplied by active forestry in Aleppo pine forests in Catalonia which could improve under active management scenarios were identified: (i) biodiversity, (ii) reduced wildfire risk, (iii) recreation, and (iv) CO_2 sequestration. ES levels and their targeted management scenarios were first draughted from the scientific and grey literature review as well as forest-related policies. Scenarios' actions, benefits and feasibility were later contrasted and fine-tuned with regional forestry expert consultation and interviews, namely technicians of the public agency devoted to private FO management and of the provincial fire prevention department, the manager of the largest FO association, and forestry and biodiversity researchers. The social demand for the enhancement of these four attributes was then assessed, however, for the purpose of this paper we focus on biodiversity and fire prevention. The ES are both non-excludable and non-rival, and thus of public good nature and benefiting the entire Catalan society.

Assuming a neoclassical microeconomic rationality, preferences are measured individually and can be aggregated. In this context, a PES attempts to align social and landowner's interests. We adopt a model where private non-industrial forest owners respond to monetary incentives maximizing their utility (e.g. Amacher et al., 2003), whereas ES beneficiaries would be ready to pay for increases of ES provision according to their perceived value (Hanemann, 1984). We acknowledge that Catalan forest owners are not just profit-motivated (see Domínguez and Shannon, 2011); however, for the purpose of simplicity we abstract from non-profit motivated considerations.

The rationale behind PES mechanisms lies in the Kaldor-Hicks compensation principle (Pearce, 1998), according to which ES beneficiaries would be ready to forgo part of the ES value in favour of forest owners who are compensated for the costs incurred in changing forest management practices that lead to ES improvements. Fig. 1 shows the payment amount being delimited on the one side by the beneficiaries' willingness to pay for ES enhancement (the maximum boundary), and on the other side, by the opportunity cost of the management change for the FO (the minimum boundary).

The payment mechanism considered gives incentives to landowners for moving from the status quo scenario (passive or timber-oriented management) towards an active management that improves biodiversity or wildfire conditions, and consequently the bundle of associated ES. As these ES are public goods, we consider the whole Catalan society as beneficiary, and hence as potential donor through an earmarked tax. The working hypothesis is that FOs are better-off in the status quo as they minimise silvicultural interventions; thus, incentives should (at least) cover the costs of the additional work requested.

This study compares whether the social benefit from marginal changes in ES exceeds the opportunity costs of enhancing the supply of these ES.

2.1.1. Opportunity cost of ES supply

Private profitability is assessed both in terms of private returns from a management scenario, and of the FO's welfare change (private gains or losses) incurred for the ES supply. To appraise private returns the FO derives from forest management we use Soil Expectation value (SEV) and annuities (aNPV) as financial indicators. We first compute the Annual Current Balance for year t (ACB_t):

$$ACB_t = R_t - C_t + S_t - X_t\ (+PES_t) \quad (1)$$

where R_t denotes the revenue from timber sales, C_t – cost of

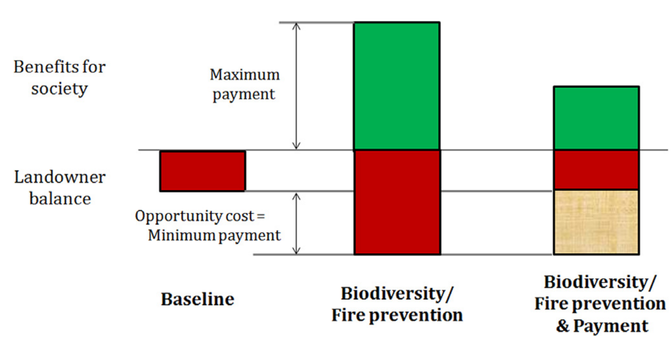

Fig. 1. Boundaries of a PES promoting active forestry. *Source*: adapted from Pagiola et al. (2004).

management interventions, S_t – possible subsidies, X_t – taxes, and PES_t – the amount that the forest owner receives for ES provision, if any. As in Catalonia there are no stumpage costs or harvesting tax, $X=0$.

When considering whether to undertake certain forest management activities or not, the FO estimates the SEV at the beginning of the cycle (t=0) reflecting the expectations for a certain silvicultural itinerary with a rotation length T, as defined by Eq. (2):

$$SEV = \frac{NPV_T}{(1+r)^T - 1}, \text{ where}$$
$$NPV_T = \sum_{t=0}^{T} ACB_t * (1+i)^{T-t} \text{ and i is the interest rate} \tag{2}$$

The SEV value can also be expressed as a stream of annual income flows of equal amounts (Zang and Pearse, 2012), the annuity:

$$aNPV = \frac{i*NPV_0*(1+i)^T}{(1+i)^T - 1}, \quad \text{where} \quad NPV_0 = \sum_{t=0}^{T} ACB_t * (1+i)^{-t} \tag{3}$$

When the FO faces several possible management alternatives, the opportunity costs (OC) indicate welfare changes derived from each alternative. OC are calculated as the difference between the SEV of these alternative scenarios (Eq. (4)), or as the difference in the respective annuities (substituting SEV by aNPV in Eq. (4)).

$$OC_{SEV} = SEV_{scenarioA} - SEV_{scenarioB}, \tag{4}$$

where A=change scenario={biodiversity, fire prevention, timber+fire} and B=baseline scenario={passive, timber}

We further assume, following Möhring and Rüping (2008), that the calculated OC represents a lower bound for the possible compensation that the forest owner would require for switching from the status quo to the desired alternative.

2.1.2. Estimating social benefits

A discrete choice experiment survey was conducted (Varela et al., in preparation) to quantify the benefits associated with changes in ES. This economic valuation method assumes that the value of a good consists of the sum of the value of all its attributes (Lancaster, 1966). It is suited to assess the social demand for the provision of a bundle of ES as it allows the assessment of the trade-offs in scenarios that represent different changes in these ES (Hanley et al., 2001).

Four attributes representing key ES -biodiversity improvement, fire prevention, CO_2 sequestration, and recreation- with four levels each were employed to describe the likely outcomes in Aleppo pine stands resulting from passive and active management scenarios (Table 1). Passive management was presented as the status quo to the valuation interviewees. A monetary attribute -an increase in regional taxes- was also included to allow the estimation of social willingness to pay for changes in the provision of these ES. Choice cards were designed to show respondents the current situation with no tax increase, plus two management alternatives entailing a tax increase. An example of the choice cards is shown in Appendix A.8. A representative sample of 410 adult Catalan citizens was interviewed face-to-face during the months of August and September of 2011.

The statistical analysis of responses is based on the random utility theory (McFadden, 1974): individuals (i) are rational and maximize their utility (U_{ij}) or welfare when choosing an alternative (j) from a finite choice set of alternatives. Eq. (5) represents the utility, where α represents the status quo specific constant; β_k is the coefficient for attribute k; x_{jk} is the level of attribute k for alternative j; and the stochastic random error term (ε_{ij}), consisting of non-observable factors affecting the choice. Parameters β vary

Table 1
Attributes and levels.

Attributes	Levels
Considered for PES boundaries' calculations	
Number of tree species (biodiversity)	1 (low)[a]
	3 (medium)
	5 (high)
	7 (very high)
Annual burned area due to forest fires (decrease in annual burned area)	1200 ha[a]
	1000 ha
	800 ha
	600 ha
Carbon sequestered by the forests equivalent to the emissions of (CO_2 sequestered)	10,000 citizens[a]
	25,000 citizens
	40,000 citizens
	55,000 citizens
Not considered for PES boundaries' calculations	
% of Aleppo pine forests suitable for recreation (Area for recreation)	10%[a]
	25%
	40%
	55%
Annual payments (increase in regional taxes)	0€[a]
	20€
	40€
	60€
	80€
	100€
	120€

[a] Status quo level.

in the population and represent individual's preferences for the abovementioned attributes. An individual chooses the alternative that renders the highest utility.

$$U_{ij} = \alpha + \sum_k \beta_k x_{jk} + \varepsilon_{ij} \tag{5}$$

The inclusion of a monetary attribute enables the estimation of the marginal willingness to pay (mWTP) for each of the non-monetary attributes. mWTP values result from computing the ratio between attribute parameters and the cost parameter. mWTP estimates allow us, by combining the different attributes and the levels these take, mimicking management scenarios and hence calculate welfare changes when moving from the current scenario to improved ES situations; these are compensating surplus (CS) scenarios. CS indicates the maximum WTP of Catalan tax-payers in a potential PES scheme for a specific scenario change. Aggregating individual CS for the entire Catalan tax-payers' population, we derive CS estimates in €/ha of Aleppo pine forests. This is a useful indicator for the forest manager, illustrating the maximum amount a PES management authority may offer to FOs for changing their forest management, after deducting transaction costs. Appendix A.7 further details the valuation approach and intermediate results.

2.1.3. PES feasibility

If CS exceeds OC, a hypothetical PES can be sketched. We contrast the private and social profitability with and without the PES. Private profitability is expressed by the changes in FO financial expectations (i.e. OC). However, social profitability has no standard definition within the PES realm: some authors consider it as the welfare change for the entire society, including the landowners - e.g. extended economic analysis in Gatto et al. (2009), while others exclude the landowner effects, that is, focus only on the welfare change for "externals" to the ES provision e.g. PES rationale by Pagiola et al. (2004). Given that a PES could be considered as a transfer, the first conception derives the same social profitability with and without PES, transaction costs obviated. We thus adopt the second conception of social profitability, where a tax-based PES means a reduction of the aggregated consumer surplus for the entire society equivalent to the payment and the corresponding transaction costs (Eq. (6)).

$$\textit{Social Profitability} = CS - tax, \text{ where}$$
$$tax = PES + \textit{Transaction costs} \tag{6}$$

To fit with the requirements for existing EU payments, the PES amount must be based on direct cost and income foregone (EU regulation 1306/2013). We therefore test two hypothetical PES amounts that lie within the boundaries defined by CS and OC: 30 and 120 €/ha/year respectively. The social profit is computed in terms of aNPV, and assumes that the flow of ES benefits derived from the management change along the agreement lasts for the entire rotation period. This assumption is needed for comparability reasons with the indicators in the absence of a PES (i.e. to keep the order of magnitude). We assess PES feasibility by checking whether the social profitability with PES is positive or not.

2.2. Case study description and management scenarios

Located in the Northeast of Spain (Fig. 2), Catalonia primarily experiences a Mediterranean climate. 60% of its territory is covered by forests, of which 80% belong to private, non-industrial FOs. Barely 29% of private forest area is managed according to a forest management plan (CPF, 2014), of which only 20% of the planned silvicultural interventions are actually implemented (Farriol, 2006).

Aleppo pine *(Pinus halepensis)* is the most widespread species in Catalonia, covering 294,000 ha of which over 204,000 ha are pure formations (Piqué et al., 2014). These stands are located along the densely populated coastal areas (Fig. 3).

Succession series have not been defined for Aleppo pine (Gil et al., 1996), as it is commonly acknowledged as a transitional stage towards broadleaved-dominated forests. The national forest inventory (Gracia et al., 2001) shows up to seven accompanying tree species for the plots in Catalonia where *P. halepensis* is the main species: holm oak, Montpellier maple, strawberry tree, wild olive tree, cork oak -in acid soils- and black pine -in the higher distribution with calcareous soils- (Herranz Sanz, 2000). Mixed open forests of Aleppo pine allow heliophilous shrubs to thrive and constitute a rich understory.

Stand dynamics of Aleppo pine in Spain have been studied from the perspective of growth modelling (Montero et al., 2001; Trasobares et al., 2004; Valbuena et al., 2008) and stand management (Beltrán et al., 2011). Field research reveals the existence of three main site quality categories of Aleppo pine stands. The site quality is associated with the potential wood market destination – sawnwood for the better site qualities, and chipping for the lower ones. Consequently, the probable management intensity performed by the landowner is linked to such potential: most FOs are passive, meaning that only selective and extractive cuttings are performed; but those with potential for higher added value products are more likely to adopt a timber-oriented forest management strategy. Our estimates correspond to medium quality scenarios, given that it is the most common in Catalonia and whose landowners may perform either passive or timber-oriented forestry.

Fig. 2. Location of Catalonia within Spain. Adapted from Wikipedia (2015).

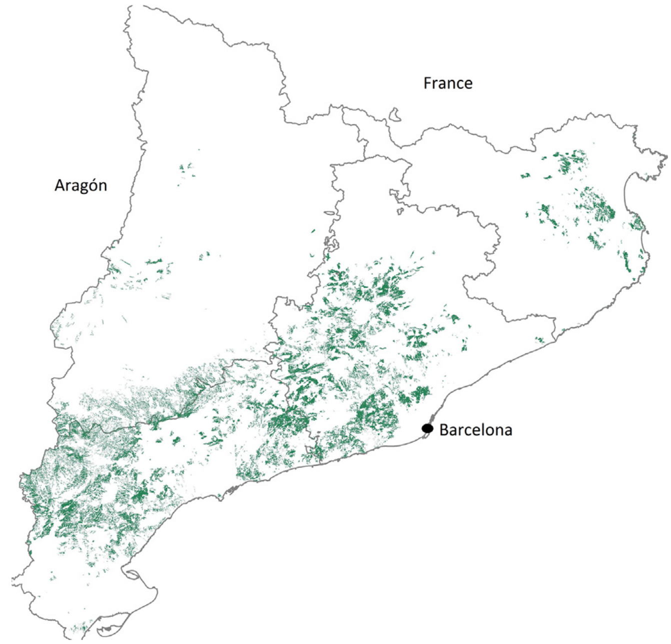

Fig. 3. Map of Aleppo pine forest distribution in Catalonia. *Source*: CREAF (2009).

Based on the ORGEST silvicultural itineraries (Beltrán et al., 2011), we developed the following hypothetical management scenarios: (i) passive, with occasional extractive timber harvests, (ii) timber-oriented, with intensive interventions, (iii) biodiversity-improvement, increasing tree species, and (iv) wildfire prevention, with a reduction in forest vulnerability. Scenarios i and ii are the most widespread, and hence have been considered as the two possible status quo situations from which FOs depart towards ES-targeted management scenarios (Fig. 4). The management costs of these scenarios are estimated both inclusive and exclusive of the current forestry subsidies.

In order to calculate the costs of enhancing ES provision, a reference forest stand of one hectare has been defined based on the National Forest Inventory data for Catalonian forests of Aleppo pine. The stand is 10 years old resulting from post-fire natural regeneration, with an initial density of 3000 trees/ha with average slope below 30%. We consider a rotation period of 100 years with current prices. The stand is located in the coastal area, with a standard density of forest roads; road maintenance work is undertaken before each forestry intervention. The stand also faces a high wildfire risk, common in Aleppo pine forests (Beltrán et al., 2011).

Natural regeneration produces a roughly even-aged forest. Most landowners manage these forests as regular (i.e. even-aged) stands; however, irregular management can be applied if the objective is to maintain mixed stands or to enhance certain

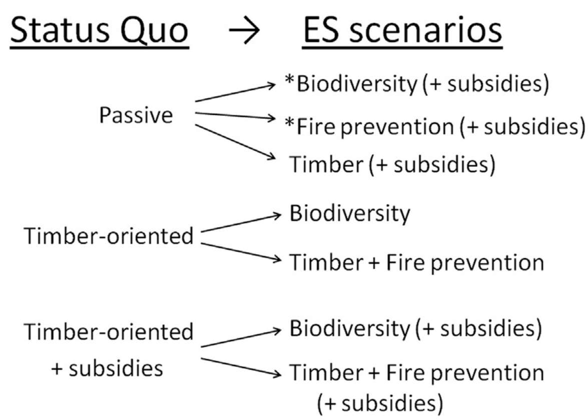

Fig. 4. Baselines and ES management scenarios used for the ES supply calculation. For social demand analysis, only management changes marked with * were considered.

Table 2
Road-side wood prices for Aleppo pine.

Normal diameter (Dg)	Price on-the-road (€/m^3)	Destination
Dg < 14 cm	11.35	Chipping/bioenergy
Dg > 14 cm	23.63	Sawnwood

broadleaved species.

Costs of forestry works are based on the tariffs of the public forestry firm (Forestal Catalana) and the estimations by Beltrán et al. (2011)[1]. Road-side timber prices (see Table 2) have been calculated from wholesale market prices and adjusted after expert consultations.

2.2.1. Passive management: selective and extractive cuttings only

This is the most common scenario nowadays. FOs do not carry out silvicultural treatments to improve their forest; instead their focus is just on occasional extraction of the best trees (i.e. trees exceeding a certain diameter, with straighter stems), a practice known as "negative selection cuttings" (Saura and Piqué, 2006). The owner implements these harvests either when facing an exceptional cash need or when the market conditions are most favourable. For this reason, we assume an intense mixed thinning at the age of 45, and a final cutting (age 90) implemented with a previous preparatory thinning (age 70). The thinning reduces the density by a quarter, with the next cuttings halving the standing timber volume. This will create large forest openings which are foreseen to be quickly colonized by Aleppo pine seedlings, due to stand maturity and the pioneer character of this species. The timber obtained in the thinnings is sold for chipping given its small diameter, while the timber resulting from the final harvest is sold for sawnwood.

The worst shaped individuals stay in the forest, hence decreasing stand quality and producing seedlings with a poorer genetic pool. Based on expert opinion, we reduced the volume productivity by 0.8 after the first and the second intervention, and by 0.6 on subsequent cuttings. In addition, resistance to fires is low due to the likely lack of gaps in the canopy and vertical continuity of vegetation stratum.

The main objective of this scenario is to maximize wood revenues on the short term with the least possible investment.

2.3. Timber-oriented, intensive management

This is the forest management approach traditionally promoted by forest engineers, which relies on production tables and traditional silvicultural treatments. The main objective is to maximize wood production, investing in improving stand quality, vitality and growth of the trees, while maintaining the even-aged structure. FOs applying timber-orientation are more likely to have a management plan approved under the rigorous sustainability criteria.

This itinerary follows the ORGEST indications, Ph05, omitting shrub cleaning operations (Beltrán et al., 2011). The management plan foresees the following interventions: (1) an initial pre-commercial thinning when the stand is aged 15 years to reduce tree density; (2) pruning of the remaining trees for shape improvement; (3) a low thinning 10 years later to remove the worst individuals (dominated or diseased) and to reduce the density to 1100 trees/ha; (4) a mixed thinning (worst-shaped individuals and commercial trees) when the stand reaches the sawnwood diameter, (5) a dissemination thinning when it is 75 years old to reduce the density to 200 trees/ha. Following that, a strong natural regeneration is expected; once it is ensured (around year 90), a final harvest is performed to extract the remaining old trees.

This scenario intuitively foresees slight improvements in biodiversity due to the larger penetrability increasing the habitat for dormant plants, small mammals and birds. Fire resistance augments given the discontinuous structure, although no specific fire prevention measures are implemented. Still, the lack of evidence for these complex wood-ES interactions makes us restrain from assigning a marginal change in ES levels as a result of implementing this scenario.

2.3.1. Biodiversity improvement scenario

High forest[2] managed as an irregular stand promotes progressive natural substitution of Aleppo pine by broadleaves, especially *Quercus* -oak- species (Valero Moreno, 2000). Therefore, tree species diversity is foreseen to improve through thinning (Gavinet et al., 2015). We thus set four different biodiversity levels for the valuation exercise, based on the national forest inventory: from only Aleppo pine to three, five or seven tree species.

The objective of this management scenario is to maximize the number of different tree species, as it will create multiple microhabitats and more varied fauna and flora (Gil-Tena et al., 2007; Torras and Saura, 2008). As a side goal, timber production is used to cover part of the incurred costs. Due to the pioneer character of *Pinus halepensis*, the conversion would be implemented by opening gaps in the stand; shadow-loving broadleaves benefit from canopy cover (Gavinet et al., 2015) and when broadleaved juveniles are well-established, selection is made on the competing pines, promoting a mixed, uneven forest.

From the initial stand, 10% of trees with the largest diameters are left unharvested and deadwood is not collected. An uneven structure with three diameter classes is established in five thinning interventions. This uneven structure allows continuity from the ground to the crown layer, and hence is prone to high intensity fires.

2.3.2. Enhanced fire prevention scenario

To our knowledge, the ORGEST manual (Beltrán et al., 2011) represents the only published silvicultural manual providing management itineraries comprehensively considering Aleppo pine growth parameters together with fire risk reduction.

ORGEST bases fire preventive silviculture on the following principles: (a) reducing tree cover to reduce intensity of potential

[1] Forestry work prices (Appendix A.5), wood price formation (Appendix A.3), the Consumer Price Index variation to compute all prices in a homogeneous base year (Appendix A.4), are available as additional material.

[2] i.e. regenerated from seeds, usual natural process in post-fire regeneration.

surface fires; (b) reducing ladder fuel (i.e. biomass continuity from the ground to tree branches) to avoid the vertical spread of fire; and (c) breaking vertical and horizontal canopy continuity for minimizing crown fire spread. The ORGEST[3] fire prevention itinerary was adapted by including our reference prices and discount rate.

The first low thinning occurs later than in other scenarios as early interventions are costly and do not create a structure significantly more resistant against fire. On the contrary, maintaining the canopy cover over 70% reduces the probability of a heliophilous shrub layer developing in opened gaps. Interventions take place every 20 years. In contrast to other scenarios, here we include shrub cleaning, pruning, and grinding of residues on a 20 metres-wide stripe along each side of forest roads.

In the period 1996–2005 the average total annual forest area burnt was of 54,000 ha, 22% of which corresponded to Aleppo pine stands. The draught of the Catalan Strategy for Biodiversity (DMAH, 2010) targets reducing the total annual burnt area to 3000 ha. With these forestry actions experts estimate that the objectives can be met, consequently setting the valuation attribute levels between the current figures (1200 ha/year) and the lowest following the strategy (600 ha/year), with two intermediate levels. No biodiversity improvements are foreseen.

For FOs located in the timber-oriented scenario as a starting point, switching to an improved fire prevention scenario would not entail a thorough change in the management practices. Rather, they would have to add an extra pruning practices plus shrub clearance and residue grinding simultaneously with other forestry actions.

2.3.3. Subsidies

All the management costs of the previous scenarios have been computed both including and excluding the subsidies that the regional government provides for some actions. Grants are restricted to FOs with a management plan (thus, passive FOs are not eligible), and cover the so-considered non-profitable interventions (i.e. dissemination and final cuttings are not covered). Subsidy amounts are listed in Appendix A.6, and are assumed to evolve in parallel to forestry costs. Most FOs implementing timber-oriented forest management in Catalonia apply for these subsidies.

3. Results

3.1. Cost of ES supply

3.1.1. Summary of scenarios results

The financial indicators are summarized in Table 3. Each scenario was calculated both including and excluding subsidies. All the scenarios without subsidies generate negative figures, even the passive management scenario although in this case the magnitude of the negative returns is substantially lower. The most negative financial indicators correspond to the fire prevention management, followed by the timber-oriented scenario. The intensity of forest works and their timing at the beginning of the rotation cycle, explain the obtained outcomes. Financial indicators for the biodiversity scenario remain negative, but are comparatively less so than in the timber-oriented or fire prevention scenarios.

The application of subsidies produce positive returns only for the biodiversity scenario but the fire prevention scenario shows significantly less negative results. This occurs mainly because most works associated to these scenarios are eligible for subsidies, as they are not profit-oriented.

Stand growth and harvest timing and intensities are summarized in Fig. 5.

[3] Specifically we use the Ph07 model.

Table 3
Summary of private returns of the different scenarios.

Scenarios	Without subsidies		With existing subsidies	
	SEV (€/ha)	**annual NPV** (€/ha*year)	**SEV** (€/ha)	**annual NPV** (€/ha*year)
Passive	−405.24	−6.78	n.a.	n.a.
Timber-oriented	−3368.01	−69.25	−586.73	−11.80
Fire prevention	−6109.94	−122.20	−1126.64	−31.09
Timber + fire	-4450.95	−89.02	−969.35	−23.47
Biodiversity	−1321.72	−26.43	91.19	1.82

n.a. = not applicable.

3.1.2. Opportunity cost calculations

Table 4 presents the costs of switching from one scenario to another, both in terms of SEV and aNPV. Positive values imply a net gain for the FO, and hence changing forest management may be in their own interest, provided other external conditions are favourable (e.g. knowledge of how to implement the new scenario or investment possibility). Negative values stand for changes in forest management that are not beneficial for FOs and where they may request compensation for such change to take place. Given that timber-oriented FOs already use subsidies, we only compute subsidies for both the initial and final scenarios.

Moving from a passive management scenario to a subsidized timber-oriented management scenario is the most usual change occurring in Catalonia; subsidies partly cover the expenses and are mainly implemented by the public agency dealing with private FO. Still, it can be observed that the FO is expected to lose with the change.

Moving from passive management to an enhanced fire prevention scenario is currently being encouraged by the Catalan public administration responsible for forest management and fire prevention. Our results show that FOs would not spontaneously undertake this management change, unless they receive substantial financial support. Indeed, even with current subsidies, financial indicators remain negative.

Finally, implementing biodiversity enhancement measures appears to provide a positive balance to the timber-oriented FOs, as they move from a very negative to a less negative scenario. This is explained by the discounting of less required interventions in the first years and their lower intensity in comparison to other scenarios.

Sensitivity analyses have been carried out with a lower (1%) and a higher (3%) interest rate. Results (Tables B.10 in Appendix B) show that the outcomes keep the same sign and order of magnitude, supporting the consistency of the outcomes. Only the option considering the move from passive to subsidized timber-oriented management becomes positive with the lowest discount rate.

3.2. Willingness to pay for enhanced ES provision

The mixed logit model used to estimate β parameters is developed in Appendix A.7. and in Varela et al. (in preparation). The marginal willingness to pay estimates per unit of each attribute are shown in Table 5.

Welfare changes of moving from the status quo situation to active management alternatives can be obtained by calculating compensating surplus (CS) scenarios. These scenarios are generated as combinations of the attribute levels resulting from forestry scenarios. Accordingly, biodiversity enhancement scenarios

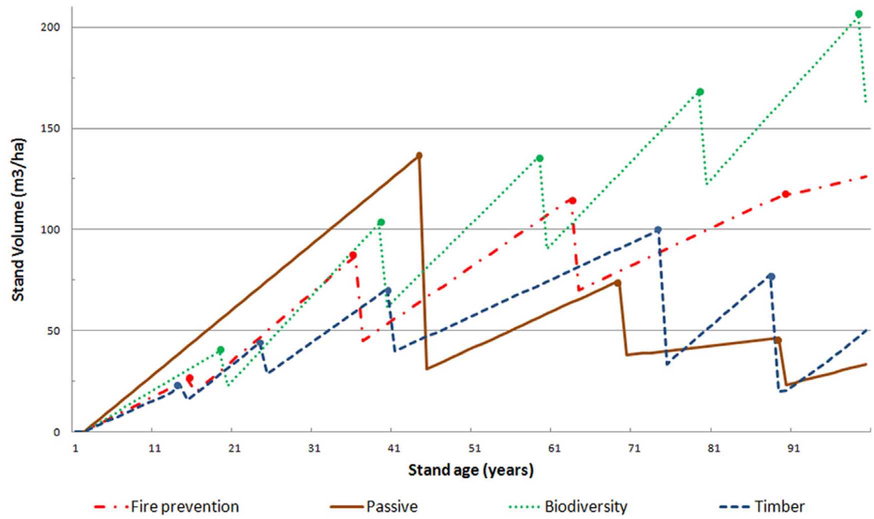

Fig. 5. Visual representation of stand growth (dotted lines) and interventions (big dots) in each scenario.

Table 4
Forest owner's opportunity costs of switching to a different scenario.

Initial management scenario	Final management scenario	Opportunity costs			
		Without existing subsidies		With existing subsidies	
		SEV (€/ha)	**annual NPV** (€/ha*year)	**SEV** (€/ha)	**annual NPV** (€/ha*year)
Passive →	Timber-oriented	− 2962.77	− 62.47	− 181.49	− 5.02
	Fire prevention	− 5704.70	− 115.42	− 821.39	− 24.31
	Biodiversity	-916.47	− 19.65	496.44	8.61
Timber-oriented →	Timber + Fire prevention	− 1082.94	− 19.77	n.a.	n.a.
	Biodiversity	2046.30	42.82	n.a.	n.a.
Subsidized timber-oriented →	Timber + Fire prevention	− 3864.22	− 77.22	− 382.62	− 11.67
	Biodiversity	− 734.98	− 14.63	677.93	13.62

n.a. = not applicable

Table 5
Marginal WTP values. Significance: ***$p < 0.001$; **$p < 0.05$; *$p < 0.01$.

Attribute	**mWTP** (€/person/year)	Confidence intervals
Number of tree species (biodiversity)	7.14***	2.89 , 11.39
CO_2 sequestered	0.0005**	0.00004, 0.001
% Area suitable for recreation	0.36*	− 0.039 , 0.75
Annual burned area	− 0.05**	− 0.087, − 0.011

(increasing biodiversity levels) and fire prevention scenarios (reducing burnt area) have been estimated, as shown in Table 6, keeping other attributes at the status quo level.

Three scenarios are considered where management is expected to improve biodiversity from a monospecific stand to three, five and seven tree species respectively; from a conservative perspective, we kept the rest of the attributes at their SQ levels. Similarly, the fire prevention scenarios differ in the burnt area reduction and maintain the rest of the attributes at the SQ levels. Compensating surplus estimates are calculated in €/person/year and in €/ha/year, taking into account the area covered by Aleppo pine forests in Catalonia, and that the total population in Catalonia over 20 years old in 2011 was 5,991,000 inhabitants (IDESCAT 2015).

The results show that the population is sensitive to changes in ES provision, with biodiversity enhancement scenarios showing larger surpluses in terms of social demand than fire prevention.

Table 6
Compensating surplus scenarios.

Management scenarios	**Attribute levels**				**Compensating surplus**	
	Biodiversity (tree species)	**CO_2 seq.** (citizens equivalent)	**Area suitable for recreation**	**Burnt area** (ha)	€ person^{-1} year^{-1}	€ ha^{-1} of Aleppo pine forest year^{-1}
Biodiversity enhancement scenarios						
BIODIVERSITY 3	**1 → 3**	10,000	10 %	1200	14.27	418.53
BIODIVERSITY 5	**1 → 5**	10,000	10 %	1200	28.55	837.07
BIODIVERSITY 7	**1 → 7**	10,000	10 %	1200	42.82	1255.60
Forest fire reduction scenarios						
FIRE 1000	1	10,000	10 %	**1200 → 1000**	9.78	286.63
FIRE 800	1	10,000	10 %	**1200 → 800**	19.55	573.26
FIRE 600	1	10,000	10 %	**1200 → 600**	29.33	859.89

Table 7
Comparison of private and social profitability, with and without hypothetical PES, in terms of aNPV.

	Biodiversity scenario	**Passive → Biodiversity** (1 spp → 3 spp)		**Fire scenario**	**Passive → Fire** (1200 ha → 1000 ha)	
	Private profitability		**Social profitability**	**Private profitability**		**Social profitability**
	Private returns	**Opportunity costs**		**Private returns**	**Opportunity costs**	
Without payment	−26.43	−19.65	418.53	−122.20	−115.42	286.63
With payment of 30€/ha/year	2.86	9.64	389.24	−92.20	−85.42	256.63
With payment of 120€/ha/year	90.75	97.53	301.35	−.20	4.58	166.63

3.3. A PES scheme

Being conservative in terms of ES increases to be achieved, we observe that even the lowest CS estimates from changes in management scenarios exceed the costs of supplying both fire prevention (286.63 €/ha vs. 115.42 €/ha) and biodiversity enhancement (418.53 €/ha vs. 19.65 €/ha). Hence, there is margin for establishing a PES scheme, for which we calculate private and social profitability (Table 7).

The social profitability is null if the landowners do not change their management. As estimated ES values correspond to changes from the passive baseline, computing social profitability for the timber-oriented baseline scenario is not possible. We neither use the passive to timber-oriented move: the lack of evidence of the intuitive ES effects (especially on fire prevention) restrains us to the conservative (but arguable) assumption that this scenario change only renders private benefits.

Social profitability is calculated for the most conservative ES values. Given the lack of transaction cost estimations, they are assumed as null. Additionally, lacking the equivalent tax estimates for existing subsidies, we limit the estimation of social profitability to those scenarios without subsidies. Interestingly, PES boundaries for fire prevention result narrower than for biodiversity, shown by their OC:CS mismatch: −115.42:286.63 for fire, and −19.65:418.53 for biodiversity. This restricts payment amount decisions.

Two contracts are offered to the FOs to modify their previous management in exchange for an annual flat-rate payment of 30 or 120 €/ha/year respectively. Assuming that all FO with Aleppo pine forest engage in the scheme, this would require an annual tax of 1.02 or 4.9 €/citizen correspondingly plus the transaction costs.

Results show that both PES modify the sign of FO outcomes when changing from the passive to the biodiversity enhancement scenario. Thus, the PES makes these changes attractive and feasible for the FO.

From the fire prevention perspective, only the higher payment provides positive OCs, even if the private return remains negative. Thus the FO only finds the fire-oriented PES interesting if amounting to 120 €/ha/year. With the lower PES, the FO would prefer to stay with the existing subsidies (−24.31) rather than entering into the PES agreement (−85.42).

Both for biodiversity or fire prevention changes, a reduction in social profit is observed in line with the order of magnitude of the PES amount. Still, social profit is positive, thus rendering feasible and acceptable the PES.

4. Discussion

4.1. On supply and demand

Our results show that most scenarios present negative financial indicators, which is in line with previous findings for Mediterranean forests (Solano et al., 2007). It provides proof to the usual FO claims that *Pinus halepensis* stands are not financially attractive for active and sustainable forest management.

The analysis sheds light on the role of the existing subsidies as a means to reduce the negative profitability of timber-oriented forest management. In fact, active Catalan FOs heavily rely on these subsidies when their primary focus is improving forest condition and wood mobilization. Subsidies become crucial to foster landowners' engagement in silviculture, hence reducing forest abandonment and improving ES levels. However, a PES complementing existing subsidies could be criticised as double payment for the same item. Thus, clear PES additionality would be required for its legitimacy (e.g. PES long-term commitment instead of the punctual participation in subsidies).

Moving from the passive or timber-oriented scenarios to the biodiversity-improvement scenario may be appealing for the landowners given the resulting welfare gains. Hence, a spontaneous management shift may be eased by improving the information available to FOs and to environmental organisations interacting with them.

Our results show that FOs already engaged in timber-oriented management face lower OC for moving to other scenarios than passive FOs do. The opportunity costs the PES-promoter should compensate are hence larger for passive landowners, in accordance with findings from other studies (Vedel et al., 2015). Still, from an environmental effectiveness perspective it may be more interesting to attract passive FOs towards active forestry, although being costlier.

Regarding the social demand, the choice experiment provides values disaggregated by ES, and thus not emphasising the management actions but the ES derived from them. The valuation exercise shows that in magnitude, WTP for biodiversity improvements largely exceeds those for CO_2 sequestration or recreation, which fits with findings of Kumar and Kant (2007). In parallel, the social demand seems larger for biodiversity improvements than for enhanced fire prevention. This result, with 2011 an average year in terms of wildfires, may be contradictory to the priority criteria that Mediterranean forest managers hold, where fire prevention is generally at the top. Moreover, this also reveals cost-value mismatches: while social welfare derived from biodiversity improvements clearly exceeds their costs of provision, values for fire prevention enhancement are relatively lower with higher supply costs. This sets narrower boundaries to decide on the potential PES amounts to reward FOs for enhanced fire prevention.

4.2. Potential PES mechanism

Responding to our first research question, results show that the lowest mWTP for forestry changes targeting ES is larger than their supply costs. This means that social profitability results positive and therefore a PES would be feasible in terms of social and FO acceptance. The simulation of two earmarked taxes shows that OCs diminish while social profitability remains positive, answering the second question. Still, the absolute financial indicators remain negative for some scenarios (fire with the larger payment, biodiversity with the lower payment), thus posing uncertainty on whether the pure economic driver becomes attractive enough for landowners. Moreover, the test of a low PES amount shows less competitive financial outcomes for the FO in front of existing subsidies. Further research is required for optimising the payment amount.

The earmarked tax suggested as the payment vehicle for fund-raising and the budget allocation through subsidy calls would fit with Kemkes et al. (2009) suggested monopsony for ES of public good nature. Transaction costs -both for the private applicant and the public institution managing the programme- have been pointed out as crucial elements in any environmental policy (Coggan et al., 2010) and specifically in PES implementation. If the PES scheme relies on institutional structures similar to the existing ones, relatively low additional costs should be expected. To cover them, our results show that there is margin for augmenting the tax (even to double it) at the cost of decreasing social profitability.

We propose a multi-year commitment, to ensure the ES improvement. Therefore, current management plans –lasting for ten years in Catalonia- should be aligned with the multi-annual contract to secure ES provision. Moreover, the simplification of ES delivery along the rotation period, and the assumption of continuous payment are not fully realistic, thus requiring further research to adjust the time lapses between actual ES supply and the payment.

A limitation of our approach is whether the stand-level changes would actually provoke the desired ES increments. Critical areas (e.g. biodiversity hotspots, key zones for wildfire spread) and adjacency effects are crucial for a finer-grained spatial targeting. Incentives coordinating the management of adjacent properties – e.g. priority criteria, or an agglomeration bonus proposed by Parkhurst et al. (2002) – can be considered in view of reducing ES uncertainties and augmenting cost-effectiveness.

4.3. Challenges and avenues for future research

Combining the results of the economic valuation exercise with the outcomes of the silvicultural models is not straightforward, and thus constitutes a limitation of the study. In valuation exercises, equilibrium has to be found between designing ecologically sound attributes and levels and, overall, securing a good understanding by the respondents (Bateman et al., 2002). This is achieved at the expenses of sacrificing some of the ecological complexity. However, most valuation studies are stand-alone exercises, and precisely one of the contributions of this paper is the attempt to translate the valuation outcomes into a real economic instrument.

Valuation results are contingent upon the time the survey was conducted and the valuation scenario. In contrast, taxation processes or medium-term contracts with FO should have some continuity for administrative efficiency and for the effective changes in forestry. A compromise should be found to compensate this time lag.

There are synergies and trade-offs in the ES provision that have not been considered when estimating the CS scenarios. This highlights the need of ecological evidence on the impacts management itineraries simultaneously produce in different ES provision. Counting with e.g. pressure-result functions (Reed et al., 2014) covering several ES would permits the design of management scenarios for joint ES provision. The choice experiment assumption of marginal ES levels behaving independently allows for building CS scenarios with different ES level combinations; this offers opportunities for designing a PES addressing a bundle of ES, but also risks overlooking actual ES trade-offs.

Further information is needed regarding FO non-economic motivations to engage in different scenarios. Timing of payment, contract duration and/or requirements may interfere with landowner risk aversion towards late payments or uncertain timber market revenues. Motivations play a role insofar as FOs may have an intrinsic incentive to cost-share or even cover the full costs if they see that required forestry actions provide them with some benefit, such as property maintenance, social recognition, fire risk reduction or with their "model to fit" (Domínguez and Shannon, 2011). These non-financial private benefits often represent hidden information that may generate informational rents, and affect overall effectiveness (Ferraro, 2008).

Finally, passive and timber-oriented scenarios present negative figures here, which is not the usual case for PES status quo analysis. Therefore even if opportunity costs are positive, it may be difficult to engage FOs. If the purpose is to achieve effective changes in forest management, then economic incentives in addition to the opportunity cost may be considered. These incentives would lie outside the PES rationale, but complement it to reach its goals; they would be feasible in case the mWTP exceeds the necessary payments along the rotation period to achieve at least neutral financial indicators (Table 7).

5. Conclusions

Negative financial indicators of traditional forestry and non-marketed ES constitute typical hurdles that forest managers face in Mediterranean forests, discouraging active forestry. Our study compares the financial analysis of forestry scenarios targeting the enhancement in the provision of key ES with valuation results assessing the social demand for their provision, in view of designing an economic policy instrument to enhance the supply of these ES. From a public economics perspective, the novelty of this study resides on its holistic, multidisciplinary approach to assess PES feasibility, encompassing forest ecology, forest management science, resource economics and environmental valuation techniques for assessing private and social profitability of forestry changes.

The estimations of PES boundaries reveal social benefits prevail over the opportunity costs of forest owners from changing silvicultural practices. Opportunity costs differ depending on whether the baseline represents a passive or timber-oriented FO. Regarding our objective, the results show the feasibility of designing a PES scheme to enhance fire prevention or biodiversity levels in Aleppo pine forests in Catalonia. The outcomes of this study also reveal some cost-value mismatches, setting a narrower margin to decide on potential PES amounts for enhanced fire prevention.

Simulating PES mechanisms fitting the existing institutional framework shows private gains in terms of opportunity costs, while maintaining positive social profitability. Still, features of contract duration, fund-raising method, and transaction costs remain to be further studied. Additional economic incentives to those covering opportunity costs might be needed to overcome the likely risk aversion due to the negative returns common to all scenarios.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ecoser.2015.11.006.

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