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RESEARCH ARTICLE

A new mechanism based on landscape diversity for funding farmer subsidies

Alejandro J. Rescia[1] · Javier Sanz-Cañada[2] · Isabel Del Bosque-González[3]

Abstract Agricultural intensification and farm abandonment in Europe have induced dramatic social, economic, and ecological issues. Sustainable management may solve these issues by providing a viable economic margin and preserving biodiversity. Specifically, we propose herein monetary compensation for farmers maintaining or restoring lands as non-agricultural areas. The mechanism for funding this compensation is based upon spatial analysis of two olive-grove landscapes. These exhibited different land-use patterns, a simple landscape and a complex one presenting a 50% higher diversity index and an 80% higher complexity index. We estimated olive-oil production and profitability. Results showed that the complex landscape contains three times more protected habitats. Neither landscape was economically viable, with the simple one showing values of 43% below the threshold, and the complex one 185%. The mechanism proposed to fund farmer subsidies was developed by means of the spatial and economic data estimated. This conservation payment system considers a non-linear relationship between the subsidies paid and the preserved area of agricultural use. The farmers of the simple landscape would receive a subsidy of 299, 394, and 464 €/ha for 10, 20, and 30% of preserved area, respectively. Inversely, the farmers of the complex landscape would be granted a reduction of 38 and 80 €/ha in their monetary incentives for the loss of 10 and 20%, respectively, of natural areas. Using this funding mechanism, conservation of biodiversity in agricultural areas would no longer constitute a factor limiting profitability, but would rather complement earnings.

Keywords Agriculture · Andalusia · Economic value of biodiversity · Environmental incentives · Olive groves · Profitability · Protected habitats

1 Introduction

Biodiversity constitutes an important input of agriculture and should be addressed, but it is often neglected by agricultural production policies. Consequently, management measures or spatial planning of conservation of biodiversity or habitats are seen as being opposed to rural development and are rejected by farmers.

In recent years, there has been growing interest in redirecting agricultural development toward sustainability by means of new approaches in resources management and environmentally friendly agricultural production. These new approaches seek to reconcile environmental impacts, biodiversity conservation, and productive agriculture (Scherr and McNeely 2008). One option of these approaches involves the land-sharing strategy, which integrates production and conservation by means of environmentally friendly agricultural management in specific croplands. The alternative option is the land-sparing strategy, which combines high-yield farming while protecting natural habitats from being used for agriculture (Green et al. 2005; Phalan et al. 2011). The land—sharing or sparing—options for agricultural areas are under conceptual and technical debate among the scholars (Von Wehrden et al. 2014).

✉ Alejandro J. Rescia
alejo296@bio.ucm.es

1   Departamento de Ecología, Facultad de Ciencias Biológicas, Universidad Complutense de Madrid, C./José A. Novais, 12, 28040 Madrid, Spain

2   Instituto de Economía, Geografía y Demografía, Centro de Ciencias Humanas y Sociales, Consejo Superior de Investigaciones Científicas, C./Albasanz, 26-28, 28037 Madrid, Spain

3   Unidad de Sistemas de Información Geográfica, Centro de Ciencias Humanas y Sociales, Consejo Superior de Investigaciones Científicas, C./Albasanz, 26-28, 28037 Madrid, Spain

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The different options for conciliation of agricultural production and biodiversity conservation are vital in Europe, because over 50% of the territory is considered to be predominantly rural and is associated with agricultural landscapes (Kotzeva 2013). These landscapes present a gradient of heterogeneity, from practically homogeneous monoculture to a diverse spatial pattern of rural activities interspersed with natural ecosystems, concentrating an important percentage of wild and agricultural biodiversity (Vos and Meekes 1999). In addition, the multifunctional condition of agricultural landscapes, associated with the delivery of ecosystem services (ES) such as rural culture, biodiversity conservation, carbon sequestration, and productivity, is currently widely admitted (García-Llorente et al. 2012; Zander et al. 2007). Within this context of multifunctionality in agriculture, farmers must be considered as producers and as managers of biodiversity conservation and as providers of ES. This multiple role of farmers must be assumed by society and should be economically supported by the administration (government or Environmental Agency). Moreover, this economic recognition could be the best way, if not the only one, to attenuate the unviable profitability of farmers in many agricultural areas. In addition, it would enable the biodiversity conservation and the ES provided by the heterogeneous components of agricultural landscapes to enhance profitability rather than reducing it (Daily and Ellison 2002).

Within the land-sharing/land-sparing debate, the profitability of agricultural areas is seldom mentioned, but it is evident that sustainable (viable) management in these areas also needs to involve a satisfactory level of profitability for the farmers, thus contributing to their sustainability in the long-term. This sustainable management to be applied in rural areas should also consider implementing payments for multifunctionality (different ES and biodiversity conservation) to farmers in order to complement their profits. Currently, numerous methods have been developed from different perspectives for the economic valuation of non-provisioning ES (Gómez-Baggethun et al. 2014), but a convincing system of payments for these services remains almost unaddressed, and the theme poses an immediate challenge to researchers, policy makers, consumers, and to the farmers themselves.

A paradigmatic case of multifunctional agricultural landscape with a small profit margin involves landscapes comprising olive crops (perennial fruit trees of *Olea europaea* L.) and semi-natural and natural ecosystems. These olive-grove landscapes are widespread in Spain and, in the Andalusia region, they cover over 1.5 M ha, concentrating a high regional range of wild and agricultural biodiversity (14% of olive groves are located in protected areas) (Bartolomé et al. 2015). In recent decades, the profitability of Andalusia olive crops

has shown a marked decrease, leading farmers either to intensify management practices or to abandon their farms (Sánchez-Martínez et al. 2011). These phenomena, very common in rural areas throughout Europe, are threatening biodiversity conservation, food supply, agricultural markets, and social cohesion (Van Vliet et al. 2015), and, particularly, the Andalusia Administration is willing to pay a complementary environmental income to farmers in order to address this situation.

Considering all this, the present paper compares two olive-grove landscapes that are attempting to attain sustainable management, considering aspects of conservation, production, and profitability. We made a comparison at landscape scale between olive-grove landscapes with contrasting land-use strategies. Specifically, we analyzed the spatial pattern of the existing land uses and protected habitats; we estimated the agricultural production and economic profitability of the olive crops and employed our previously estimated spatial and economic data to propose a system of public payments to farmers in order to maintain a diversity of habitats at the landscape scale, and consequently to increase profitability and conserve biodiversity.

2 Material and methods

2.1 Study area

The study area included two districts (*comarcas*) in the Andalusia region, *Estepa* and *Sierra de Segura*, falling within the Protected Designations of Origin of Extra-Virgin Olive Oil (Fig. 1). The *Estepa* district occupies approximately 78,000 ha and is relatively flat (maximum altitudes of below 800 m a.s.l.), presenting an agricultural landscape in which olive crops are the predominant land use. There remains only a sparse remnant of natural vegetation (holm oak Mediterranean forests) and some semi-natural areas, essentially *dehesas* (agro-silvo-pastoral systems comprising a continuous matrix of grassland with scattered trees). The *Sierra de Segura* district covers a mountainous area (ranging from 500 to 2000 m a.s.l.) of over 200,000 ha, with olive crops occupying a reduced area and many of these falling within the "*Sierras de Cazorla, Segura y Las Villas*" Natural Reserve. The natural vegetation is predominantly characterized by endemic Spanish black pine (*Pinus nigra* subs. *salzmannii*) and some formations of deciduous trees and sclerophyllous plants, together with *dehesa*s. The predominant climate in both areas is Mediterranean with an average annual rainfall of between 500 and 700 mm (in the higher parts of the *Sierra de Segura*, it can reach 2000 mm) and an annual mean temperature of 16 °C.
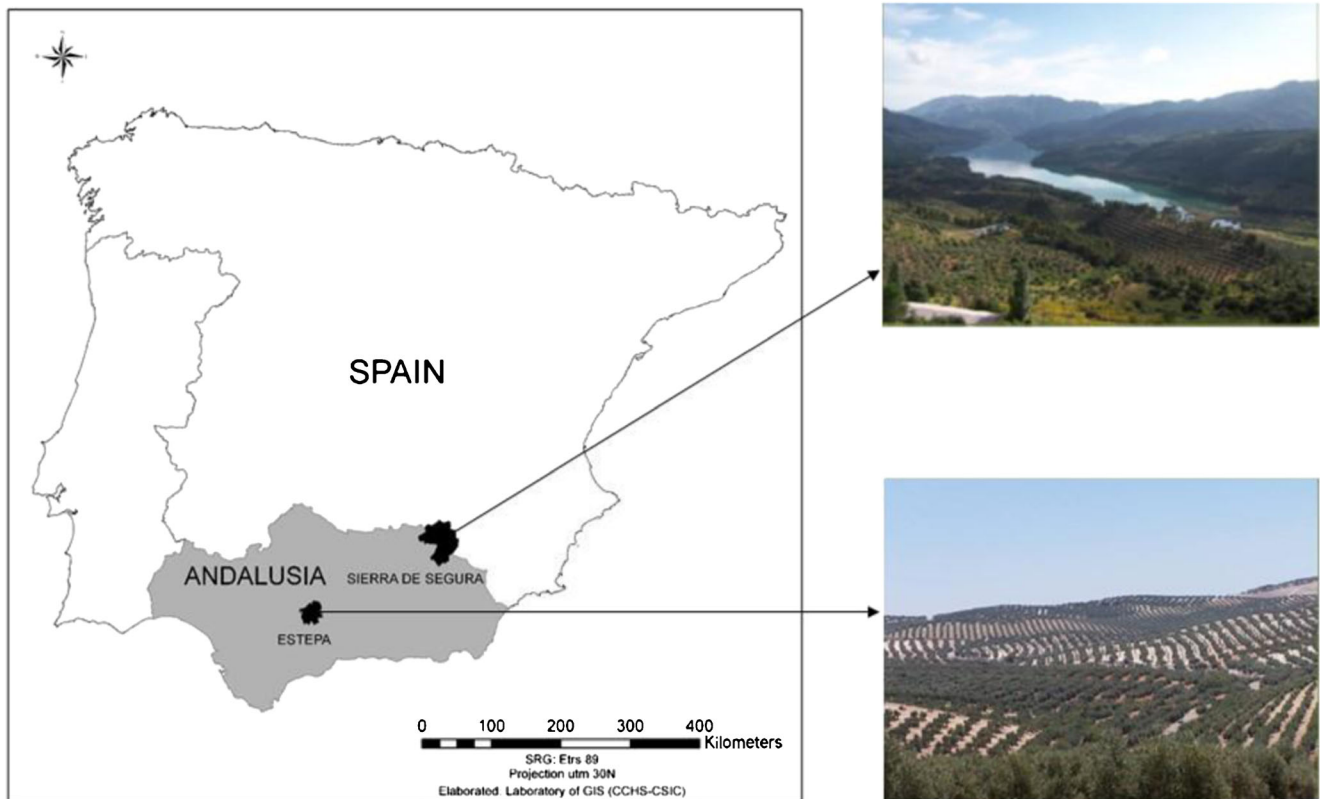
Fig. 1 Location and partial view of the agricultural landscapes studied. *Estepa* presents a land-use strategy more adapted to the land-sharing option (olive crops with semi-ecological management but scarce natural areas) and *Sierra de Segura* adapted to the land-sparing option (olive crops spatially concentrated and preserved natural areas)

2.2 Data acquisition and analysis

In order to analyze the spatial structure of the landscape, we used an original complete land-use map (from the year 2007) adapted from the Land Cover and Use Information System of Spain, developed by the Andalusia Environmental Department (LCUISS 2005). This classification was adjusted to the resolution level (1:25,000 scale) and the objectives of the research. We used landscape structure as an indicator of biodiversity conservation due to its matrix effects and habitat diversity (Cunningham et al. 2008). At the same time, the spatial structure detected enables us to infer ecological functions linked to the potential restoration and provision of ES (Hardman et al. 2016; Stallman 2011). Essentially, composition and spatial configuration of the landscape determine different horizontal flows (energy, materials), condition ecological processes, and provide regulation and supporting ES. To factually quantify the value of conservation of the landscape structure, we analyzed the presence and spatial configuration of habitats protected (or of conservation interest) by European and Spanish conservation regulations, using the map of protected habitats established by the European Union Habitats Directive (EUHD 1992).

Specifically, for these spatial analyses, we applied a set of selected landscape metrics (avoiding redundancy of information) from the Fragstats 4.0 software and other metrics based on the Theory of Information (for details of these metrics, see also McGarigal et al. 2012; Rescia et al. 2010). The landscape metrics used were as follows:

As a fragmentation index:

Interspersion and Juxtaposition Index (IJI) $= \frac{-\sum_{i=1}^{m}\sum_{k=i+1}^{m}\left[\left(\frac{e_{ik}}{E}\right).\ln\left(\frac{e_{ik}}{E}\right)\right]}{\ln(0.5[m(m-1)])}.100$; where e_{ik}: total length (m) of edge in landscape between land-use classes i and k; E: total length (m) of edge; m: number of land-use classes.

As a connectivity index:

Mean Euclidean nearest neighbor (ENN_MN) $= \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} h_{ij}}{N}$; where h_{ij}: distance (shortest straight line) from patch ij to nearest neighboring patch of the same type (class); ENN $= h_{ij}$, at patch level.

As diversity and complexity indices:

Landscape diversity (LH′) $= -\sum [p_{i/j}*\ln(p_{i/j})]$; where $p_{i/j}$: proportion of the land-use patches i and j considering the total number of patches (NP) ($\sum p_{i/j} = 1$) and landscape

complexity (LC) = LH′²/lnNP; where LH′: landscape diversity and NP number of patches.

As a dominant land-use of the landscape index:

Largest Patch Index (LPI) = $\frac{max_{j=1}^{n}\left(a_{ij}\right)}{A}$ (100); where aij = area (m²) of (largest) patch ij and A = total landscape area (m²).

To estimate agricultural production, two main farming management types of rain-fed olive crops can be identified in the study area: the traditional one (i.e., extensive) and the intensive one. Therefore, the rain-fed olive crops were classified according to terrain slope (possibility of using machinery, depending upon steepness) and tree density: non-mechanized traditional olive groves (NMTO) with slope >20% and <200 trees/ha; mechanized traditional olive groves (MTO) with slope <20% and <200 trees/ha; intensive olive groves (IO) with slope <20% and >200 trees/ha. Each farming type presents a different olive-oil yield: 350 kg oil/ha for NMTO; 700 kg oil/ha for MTO and 1000 kg oil/ha for IO. The three systems involve different operational costs (i.e., agrochemicals, labor, and machinery, among others). The classification criteria and data were based on studies and official statistical data at the local and regional levels (MAFE 2012; Sanz-Cañada et al. 2015).

For estimated profitability of olive oil production (€/ha), we analyzed the production stage of the value chain consisting on three stages: production (farming), transformation (industrial), and distribution (commercial). The reference farmer selling prices for the olive oil, as well as the costs, were considered for the 2007/08 period, as this corresponded to the landscape structure in the analyzed districts in 2007. Furthermore, the single payments introduced in the economic analysis, granted to farmers regardless of production type, refer to the European Single Payment Scheme established in the reform of the Common Agricultural Policy (ECR 2003). The values estimated were based on studies and official statistical data at the local and regional levels (POOLRED 2016; Sanz-Cañada et al. 2015).

For valuation of environmental payments to olive farmers, we developed a mechanism, using an allometric equation, based on the criterion that the government (administration) would be willing to pay to a certain percentage of the areas preserved for agriculture following a scaling relationship, that is, a positive power function between the payment and the area preserved. The allometric equation proposed is:

BioEcoS-P = *a**NAA^b, where, *BioEcoS-P (Biodiversity and Ecosystem Services Payments)* is the dependent variable and denotes the environmental subsidy to be paid by the government (€); *a* is a normalization constant parameter; *NAA (Non-Agricultural Area)* is the independent variable representing the percentage of the total area covered by protected habitats, as well as semi-natural and natural vegetation excluding crops; and *b* (being *b* < 1) is the allometric exponent. This exponent represents the dynamic rules at play in the payment system, that is, the scaling relationship used to pay for the conservation area "designated" subjectively by the government. Subsequently, as the *NAA* increases, the *BioEcoS-P* increases in an approximately logarithmic manner. The starting value of *BioEcoS-P* and *NAA* in the allometric equation was determined by means of our results of the spatial analysis of the landscape and by the economic analysis of the olive-grove production system and considering the minimum threshold value of profitability economically viable for the Andalusia Region. The *b* value was determined by fitting the allometric equation to the difference between the subsidies paid to farmers in both study cases.

3 Results and discussion

3.1 Landscape structure

Table 1 shows that almost 90% of *Estepa* comprises agricultural land-uses, whereas these only represent 27.66% in *Sierra de Segura*, considering that rain-fed olive crops represented 63.39% in the former case and 21.54% in the latter. In *Sierra de Segura*, the presence of wooded formations, *dehesas*, scrubland and grasslands was very significant (68.46%), while in *Estepa*, natural and semi-natural land-uses covered only 6.87% of the territory. The value of the metrics evidenced that the landscape of *Sierra de Segura* was similarly fragmented (IJI), but better connected (lower value of ENN_MN) and more diverse and complex (greater value of LH′ and LC) than the *Estepa* landscape. The relatively low value of fragmentation of *Estepa* resulted from the large clumped patches of olive crops but, at the same time, it presented small and disconnected areas of non-agricultural land-use patches (a high value of ENN_MN).

3.2 Protected habitats, production, and profitability

Table 2 reveals a highly contrasted presence of natural and semi-natural vegetation giving rise to a greater number (39 in *Sierra de Segura* and 13 in *Estepa*) and greater area (TPHA), representation (PPA), size (AREA_MN), clumping (IJI), diversity (LH′) and complexity (LC) of protected habitats in *Sierra de Segura*. Table 3 shows that olive-oil production per hectare was greater in the *Estepa* district (732 and 468 kg of olive oil/ha, respectively) because the *Estepa* district presented a wide area covered by olive crops that are mechanized, presenting greater productivity than the non-mechanized crops, which represent the majority in *Sierra de Segura*. Moreover, in *Estepa*, there were considerably more

Table 1 Spatial structure of the agricultural landscapes studied defined by different landscape metrics and relevant characteristics such as area, proportion of the total area, mean size, and largest patch of the main land-use types identified. Both landscapes were divided into agricultural and non-agricultural areas

Spatial features and land-use/ cover types	Estepa	Sierra de Segura
Landscape structure		
Fragmentation (%)	55.67	60.58
Connectivity (m)	289.54	192.15
Diversity (nat)	1.36	2.03
Complexity (nat)	0.23	0.42
Agricultural area (crops)		
Rain-fed olive crops (ha/%)	49,554/63.39	46,704/21.54
Irrigated olive crops (ha/%)	321/0.41	704/0.33
Abandoned olive crops (ha/%)	99/0.13	205/0.99
Other crops (ha/%)	17,784/22.74	12,376/5.7
Mean area of olive crops (ha)	113.15	35.89
Largest patch (olive crop) (% of total area)	16.44	5.47
Non-agricultural area (semi and natural cover)		
Forests and plantations (ha/%)	682/0.87	41,830/19.3
Grasslands and scrubland (ha/%)	2541/3.25	44,282/10.43
Dehesas (semi-natural cover) (ha/%)	2151/2.75	62,290/28.74
Other non-production land-uses (ha/%)	5043/6.46	8392/3.87
Mean area of natural patches (ha)	7.64	13.65
Largest patch (% of total area)	0.96 (shrubs)	7.23 (*Pinus* forest)

highly productive intensive olive systems than in *Sierra de Segura* (7473 and 467 ha, respectively), thus accentuating the difference in production.

Taking into account that production costs depend on the quantity and the way of the olive oil produced, these costs were substantially higher in *Estepa* (1536 and 1227 €/ha, respectively) due to the abundance of mechanized and intensive management systems. Finally, total profitability was observed to be greater in *Estepa* than in *Sierra de Segura* (704 and 350 €/ha, respectively), although the low level of profitability should be highlighted in both cases. The direct European Single Payments slightly compensate for the low income in the both districts but it should, however, be pointed out that profitability in the *Sierra de Segura* district was negative (−42 €/ha) when these payments were discounted.

Table 2 Conservation value of the agricultural landscapes studied estimated from the spatial structure of the habitats protected by European and Spanish regulation

	Estepa	Sierra de Segura
Protected habitats		
Total area (ha)	4022	139,997
Percentage of total area (%)	5.14	64.58
Richness of patches	13	39
Mean area of patches (ha)	5.99	56.47
Interspersion of patches (%)	27.79	63.38
Diversity of patches (nat)	1.41	2.31
Complexity of patches (nat)	0.31	0.69

3.3 Payment mechanism for biodiversity conservation

Figure 2 shows the proposed *BioEcoS-P* scaling payments to farmers for the percentage of natural area excluded (or restored) from the agricultural use. According to this scheme of payments, the farmers would receive high monetary incentives for the first 10% of area excluded from agriculture and

Table 3 Production value and economic profitability of both agricultural landscapes estimated from the stage of production of the value chain analysis of extra-virgin olive oil. Only rain-fed olive grove equivalent area was considered (value adjusted to the smaller olive crops area of *Sierra de Segura*)

	Estepa	Sierra de Segura
Olive crops		
Total area (ha)	46,704	
Crop systems (ha)		
Non-mechanized management	2335	31,292
Mechanized management	36,896	14,945
Intensive management	7473	467
Production (kg olive oil/ha)	732	468
Farmer selling price (€/kg olive oil)	2.53	
Production costs (€/ha)	1536	1227
Single payments (€/kg)		
Non-mechanized management	1.12	
Mechanized management	0.56	
Intensive management	0.39	
Production incomes (€/ha)	2240	1577
Profitability (€/ha)	704	350

BioEcoS-P (€)

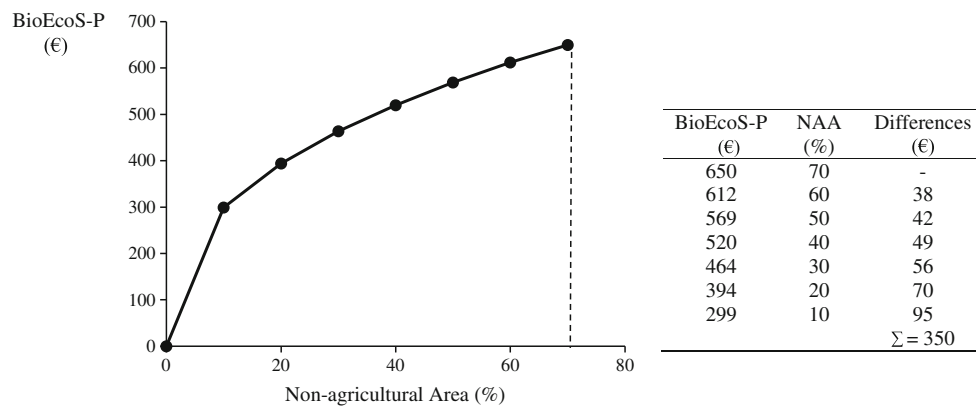| BioEcoS-P (€)	NAA (%)	Differences (€)
650	70	-
612	60	38
569	50	42
520	40	49
464	30	56
394	20	70
299	10	95
		$\Sigma = 350$

Fig. 2 Mechanism of payments of the biodiversity conservation and ecosystem services (BioEcoS-P) according to percentage of non-agricultural area (NAA) preserved in relation to the total area of the agricultural landscape considered. The percentage of preserved area increases and payments for this conservation decision increase, following a power relation for $a = 119€$ and $b = 0.40€$. The b value was determined to compensate the difference in profitability/ha between both districts, taking into account their non-agricultural area. The values on the right of the figure correspond to the indicated points and were calculated following the formula: $BioEcoS\text{-}P = a*NAA^b$

would progressively receive lower payments for every 10% of land preserved. In the Andalusia region, the minimum threshold value of profitability considered economically viable for olive crops corresponds to an average value of practically 1100 €/ha (ESC 2011). Assuming that the administration would consider a threshold profitability value of 1000 ha, slightly lower than this regional minimum, but better adjusted to the national average value, in *Estepa*, presenting approximately 10% of non-agricultural land, the farmers would initially receive a habitat conservation subsidy of 299 €/ha, and in *Sierra de Segura*, with approximately 70% of non-agricultural land, they would be paid 650 €/ha. Thus, in accordance with the allometric scaling payments proposed, in *Estepa*, the farmers would receive 394 €/ha for abandoning the first 10% of agricultural land, 464 €/ha for the following 10% of agricultural systems abandoned, and so on. Inversely, *Sierra de Segura* would see a reduction of 38 and 80 €/ha in their monetary incentives for the loss of 10 and 20%, respectively, of natural areas, and so forth (see Fig. 2).

3.4 Economic valuation of biodiversity conservation as a profitable solution for agricultural landscapes

Many studies of agricultural landscapes have detected the direct and positive relationship between spatial heterogeneity (variety of land uses) and complexity (degree of connectivity), on one hand, and biodiversity (Benton et al. 2003), potential capacity for restoration (Hardman et al. 2016) and the provision of ES, such as biological pest control and pollination (Kremen et al. 2007), on the other. Indeed, several authors (Groves et al. 2002) have indicated that, for an effective biodiversity and ES conservation in agricultural landscapes, there is a need to consider a broader spatial perspective than mere

environmental practices in the farming system, i.e., the landscape context.

At the same time, Daily and Ellison (2002) emphasized that the economic profitability of farmers is vital to sustainable management of biodiversity in agricultural landscapes. Within this vision of profitable conservation in agricultural landscapes, we consider that an effective solution to the unprofitability in the olive grove landscapes studied could simultaneously be based on intensifying agricultural patches (improving profitability) and maintaining natural patches or restoring these by abandoning olive crops (improving biodiversity conservation). This kind of "win-win or bioprofit strategy," which would be applied to different agricultural landscapes (see Mouysset et al. 2014), would be highly appropriate for the olive groves studied in Andalusia. Specifically, in *Estepa*, farmers should gradually, and in controlled manner, abandon the less productive olive crops with a slope >20% (over 2000 ha), with close to 100 t ha^{-1} year^{-1} of soil erosion (Gómez and Giráldez 2010) intensifying other current crops on more arable land. In *Sierra de Segura*, farmers could increase productivity and profitability by intensifying farming management of olive crops located on non-sloping terrain (over 10,000 ha < 20% slope) and maintaining large natural areas for biodiversity conservation.

However, it is not enough to implement this strategy based upon intensification practices and crop abandonment to achieve a viable degree of profitability in the olive-grove landscapes studied. By intensifying olive crops, farmers would receive an increase of approximately 12 €/1000 ha (calculations based on the data in Tables 2 and 3) and, in addition, they would cause environmental degradation and have an impact on landscape diversity, affecting biodiversity, as well as the delivery of multiple ES. Therefore, public (or private) economic compensation for farmers for the cost of

maintaining and restoring natural areas for conservation objectives, or for profits lost thereby, is a necessary alternative with regard to improving profitability. The system of payments or financial incentives for restoring or maintaining natural areas proposed in our study aims to meet both objectives: conservation benefits and profitable farming. This system of incentives is based on a criterion involving adjusting payments to a progressive process of diversification of the agricultural landscape, in accordance with a scaling law (see Fig. 2). Other incentive-based policy designs for environmental subsidies were developed or discussed (De Vries and Hanley 2016; Pascual and Perrings 2007), but always within the framework of uniform (not differentiated) payments and without spatial reference. The type of regime of progressive payments proposed here is essential with regard to determining the cost of the "biodiversity conservation" that should be paid to farmers to improve their profitability.

4 Conclusions

Different spatial structures of agricultural landscapes have different consequences for biodiversity conservation, potential ecological restoration and provision of ES. Our results showed the advantages for habitat conservation (13 vs. 39 protected habitats) in the more diverse and complex landscape structure. In economic terms, despite the general subsidies paid by the European Union, the different spatial structures analyzed (basically monoculture vs. crops mixed with natural vegetation) are impracticable due to the fact that profitability for farmers is far from the minimum level considered to be viable in this region.

We propose an economic incentive-based mechanism, to be managed by the administration (public policies) to promote levels of landscape diversity and complexity that are more suitable for biodiversity conservation. These economic incentives would complement the profits of farmers and can constitute, pending further validation, a sustainable solution for conciliating conservation, production and profitability in agricultural areas. In this context, conservation of biodiversity in agricultural landscapes ceases to represent a factor limiting the profitability of farmers, but rather serves to increase profits. In Andalusia, this system of incentives could be applied immediately under the auspices of the recent Olive-Grove Master Plan (ORGAB 2015), which specifically mentions economic support for farmers implementing environmentally friendly farming practices and applying improved spatial management; the aforementioned practices are intended to promote biodiversity, provide ES and to maintain landscape quality (assuming a heterogeneous structure).

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